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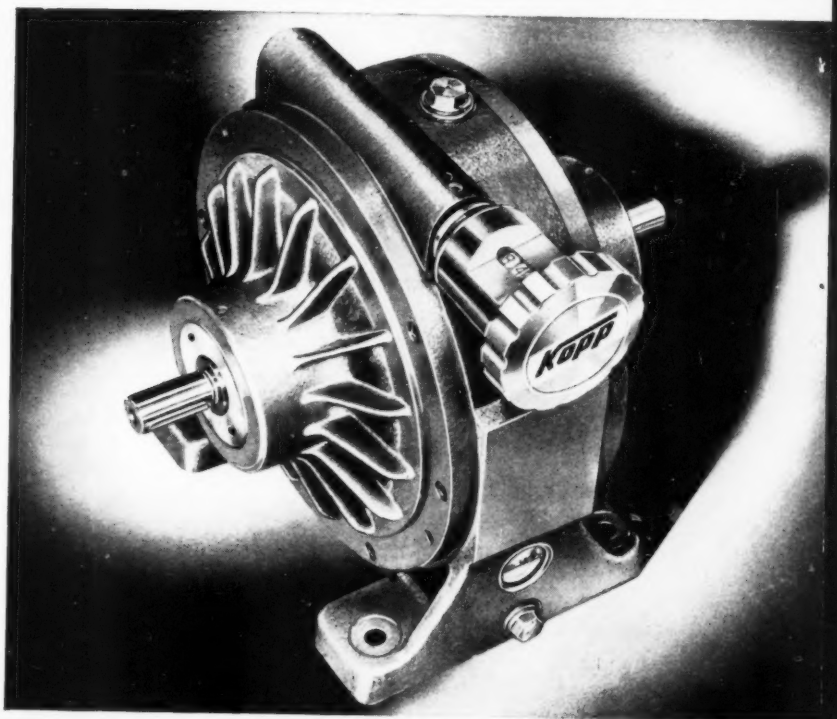

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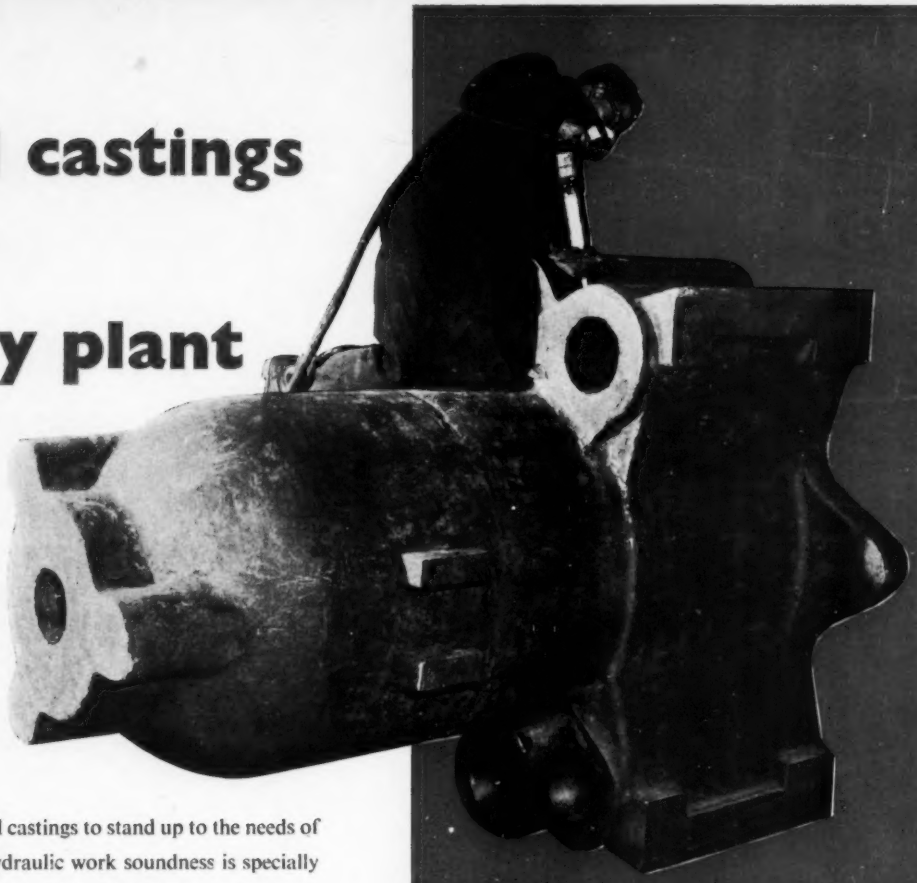

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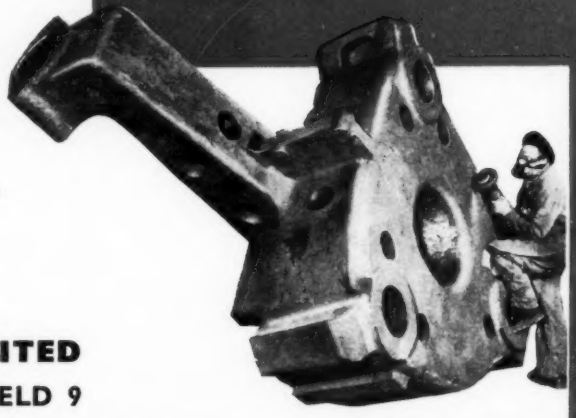

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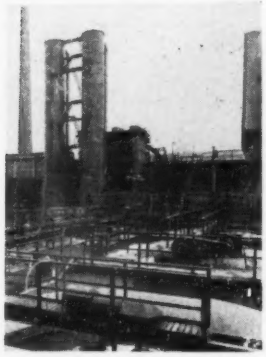

A view of a plant designed for the oxidation of phenolic waste liquor from an ammonia still. An article describing this plant, stressing the economics of the problem, is part of the CPE survey on effluent control.

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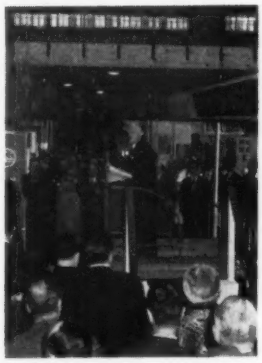

Sir Alexander Fleck opening the Corrosion and Metal Finishing Exhibition held recently at Olympia. A full report of the exhibition appears in this issue.

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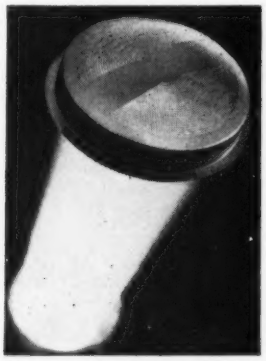

The material of construction for chemical plant discussed this month is platinum. The picture shows a platinum jet with over 2,000 orifices which is made and used in the production of staple fibre by Courtaulds Ltd.

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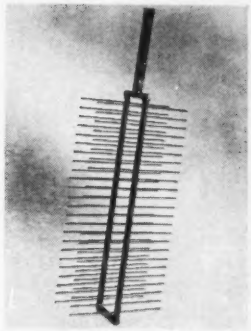

A typical titanium anodising jig as shown above illustrates one of the many applications of titanium in the chemical industry. Titanium is the material of construction for chemical plant which is discussed this month.

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The scope and significance of Churchill College, Cambridge, is described in a specially contributed article by Mr. J. A. Oriel, past-president of the Institution of Chemical Engineers, who was recently appointed a Fellow Extraordinary at Churchill College.

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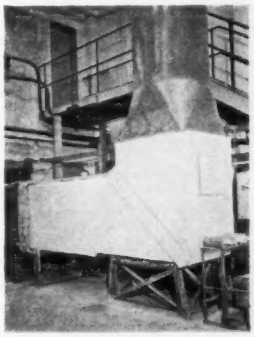

An atmospheric pressure test rig, illustrated above, formed part of the plant used in examining transient behaviour of counterflow heat exchangers.

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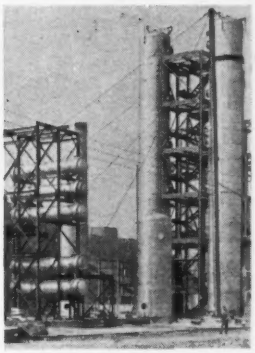
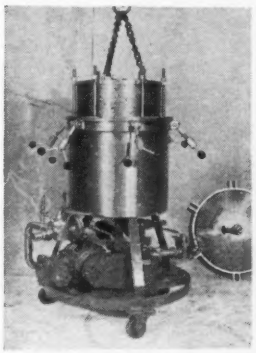


The picture shows various items of aluminium plant during erection for the manufacture of hydrogen peroxide. The use of aluminium as a material of construction for chemical plant is described in an article by J. C. Bailey of the Aluminium Development Association. PAGE 137

A high-speed centrifugal ball mill suitable for preparing dispersions of carbon black, Prussian blue, etc. R. V. Riley, in his review on size reduction, surveys new developments in this field. PAGE 117



A 3-sq.-ft. model high-duty pressure filter from which scale-up data for larger units can be obtained. This subject is discussed in an article on scale-up for drying and filtration plant. PAGE 113

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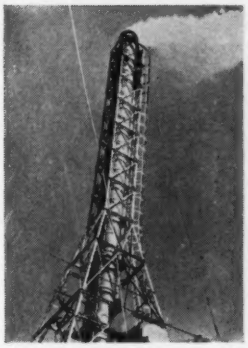

This chimney, made of reinforced plastics, must withstand windloads up to 90 m.p.h. and be resistant to strong acid vapours. It demonstrates the versatility of reinforced plastics which are featured as this month's 'Materials of Construction for Chemical Plant'

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Dr. J. H. Burgoyne of Imperial College, London, has contributed an article on 'Principles of Explosion Prevention' which forms part of the special feature on Safety in this issue

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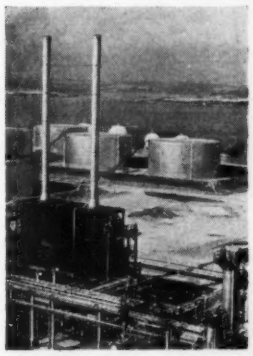

The Whitegate oil refinery forms part of the small but expanding chemical industry in Ireland. The prospects of this chemical industry are discussed in a special article

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Illustrated on left:

2½-ton Liquid Argon Transportable Tank, fabricated in Aluminium to B.S.S. 1477—Grade NP5/6(0) and comprising an inner vessel 3′ 6¼″ O/D by 7′ 4″ long on the straight, supported on four insulated support blocks inside a jacket 5′ 0″ I/D by 8′ 8″ long on the straight. The jacket is stiffened by means of two channel rings and supported on Mild Steel skids. All of the connections, except the explosion disc, comprising the vacuum branch, argon lines and instrument lines are brought out at one end of the tank where the valves and instruments are housed inside a canopy. The interspace between the jacket and inner vessel is filled with insulating powder. *Inner Vessel*—designed for 115 p.s.i. and tested 175 p.s.i.g. hydraulic. *Jacket*—vacuum tested to .01 mm. Hg absolute

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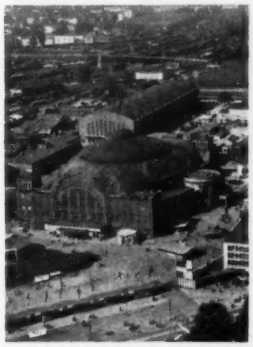
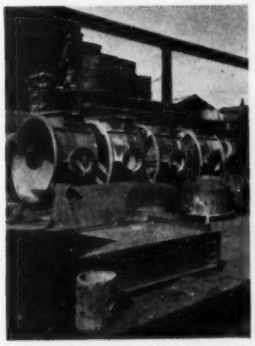
Pipelines from the B.P. Aden oil refinery to the oil harbour being welded together. The operation and economics of pipelines are discussed in an article 'Pipelines in the Oil Industry' which form part of a specia feature on Pipelines. PAGE 199



The 13th Achema exhibition is taking place in Frankfurt-am-Main from June 9 to 17, 1961. Our special exhibition preview surveys some exhibits of particular interest to chemical engineers. PAGE 212



A view of heavy castings for use in the chemical industry. Cast iron, the oldest chemical construction material, is discussed in our series on 'Materials of Construction for Chemical Plant' PAGE 225

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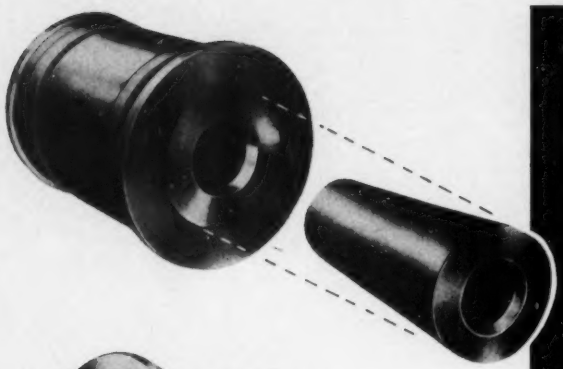

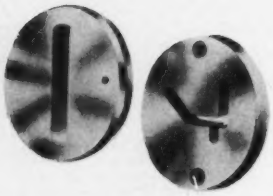

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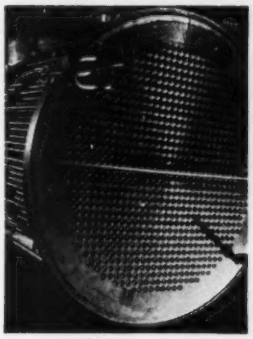
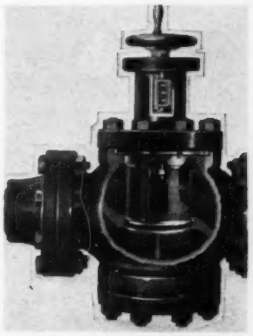
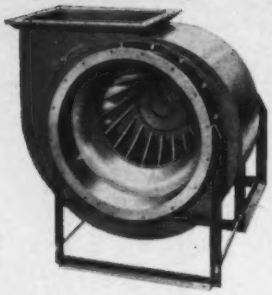


Final assembly of a mild-steel tubular heat exchanger made by Head Wrightson Teesdale Ltd. Mild steel is the material of construction for chemical plant which is discussed this month. PAGE 271

Dr. F. Molyneux, who is well known to our readers, has contributed an article on the design of a spray dryer used in the manufacture of lithopone. PAGE 247



A standard metering valve which forms part of a continuous in-line blending system which is capable of blending two oils at a specified ratio without the use of complex instrumentation. PAGE 251



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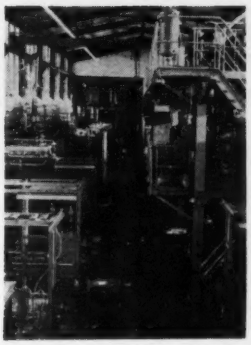
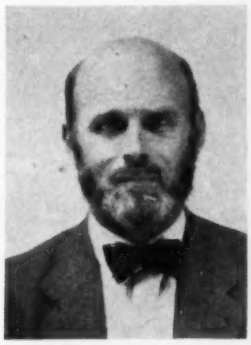


View of one of the chemical engineering laboratories at the Technical University, Delft, Holland. The function and scope of these laboratories in training chemical engineers is discussed in a special article PAGE 297



Mr. K. L. Butcher, in his fifth article on 'Chemical Engineering Fundamentals', discusses unsteady-state heat transfer and methods of solving differential heat transfer equations
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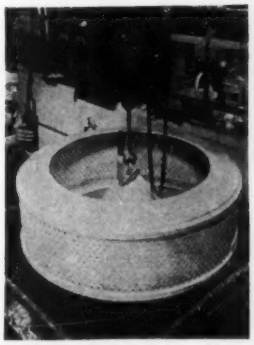

A large centrifuge basket, with an electro-deposited silver lining 0.01 in. thick over all surfaces, illustrates one application of silver as a material of construction for chemical plant
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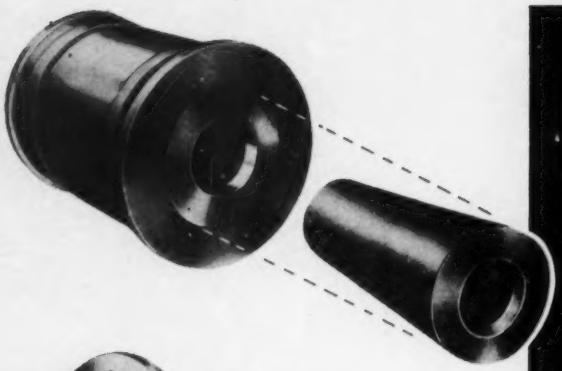

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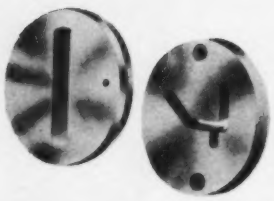

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An instrument store at one of the N.I.F.E.S. stores. An investigation by this organisation into fuel efficiency in the chemical industry is described.

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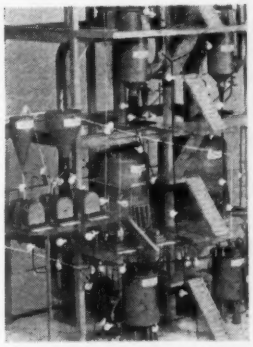

A model of a 'Krystal' plant for the production of benzoic acid crystals. The annual unit operations' review on crystallisation reports many interesting processes in the heavy inorganic and petrochemical industries which incorporate crystallisation at one stage.

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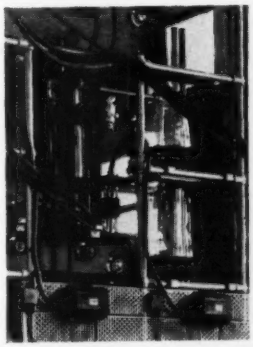

An ion-exchange column illustrates one use of glass as a material of construction for chemical plant. The growing acceptance of glass in the chemical industry is discussed in a special article.

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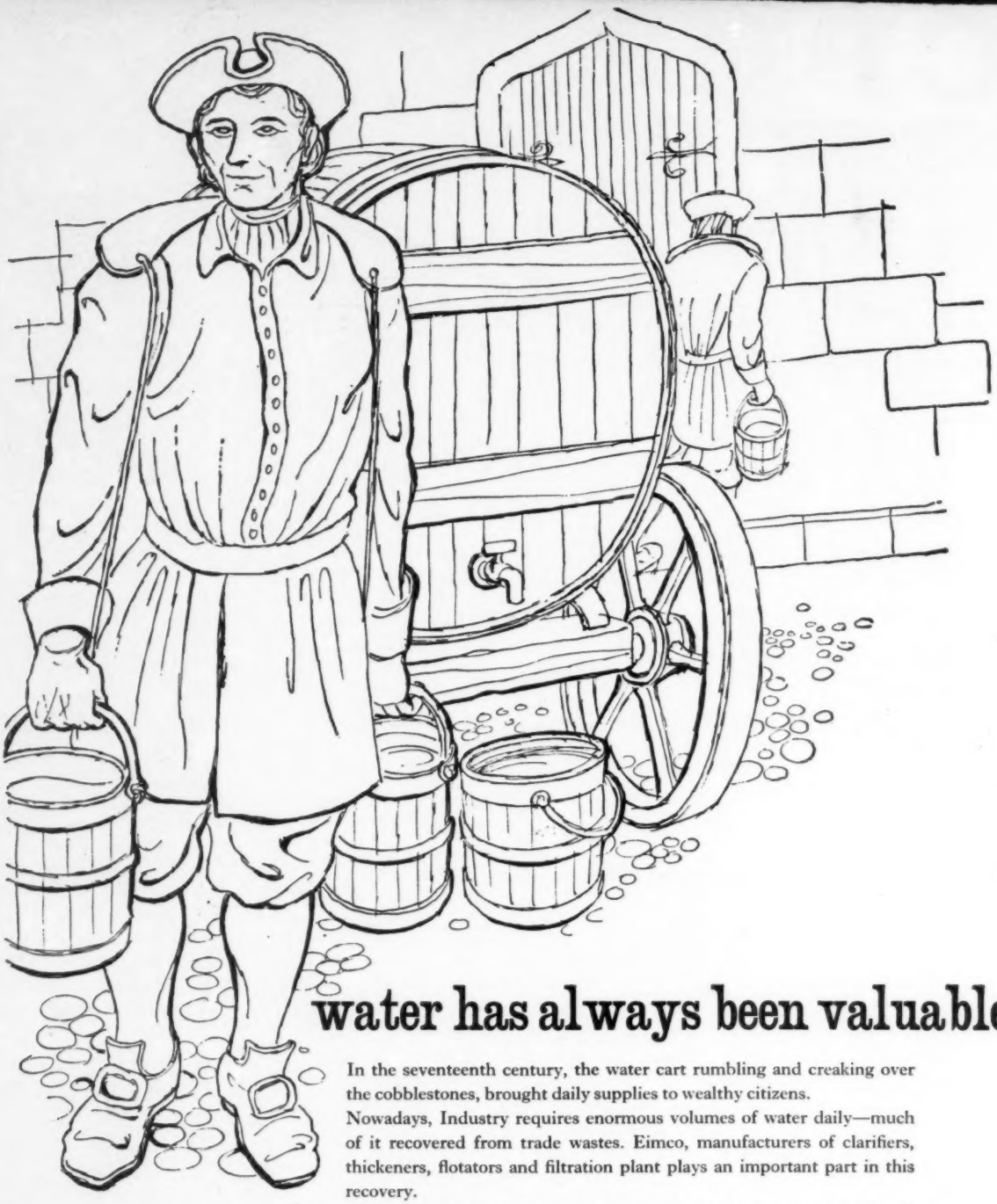

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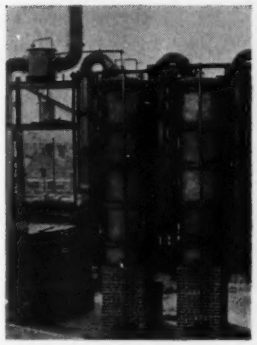
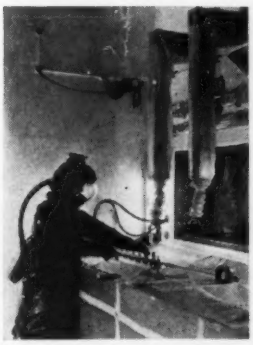


A battery of chemical stoneware towers for washing fumes and reclaiming acid—these are one particular application of ceramics as a material of construction for chemical plant PAGE 405

Mr. T. Irvine Hudson, the well-known water engineer, describes some present-day processes for obtaining fresh water from saline sources. This article forms part of a special feature on water desalination PAGE 387



A frogman decontaminating the working surface of a high-activity handling building at Harwell. Several methods of assessing safety in the nuclear industry are surveyed by A. Quinton in Part 1 of his article PAGE 402

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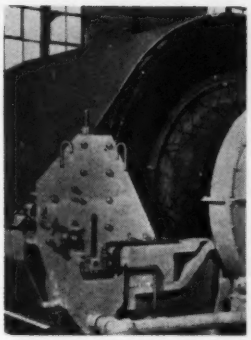

An 'EimcoBelt' filter, suitable for direct filtration in the sugar industry, is shown in the annual unit operations review on filtration by H. K. Suttle

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Mr. J. F. Roth, author of the article 'Applications of Computers to Process Control,' seen seated at the control desk of a computer-controlled data. processing system. This article forms part of a special feature on computers

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View of wrought and machined beryllium components. Beryllium forms one of the new metals group which is discussed in this month's 'Materials of Construction' article

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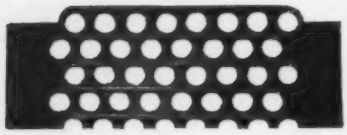

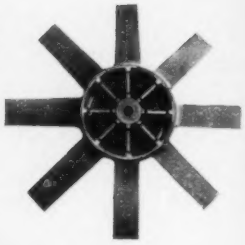

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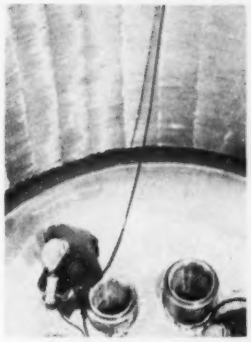
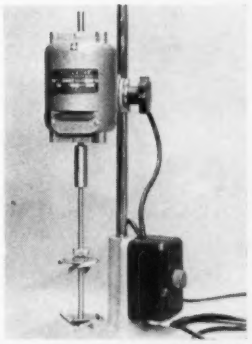
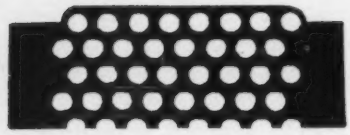


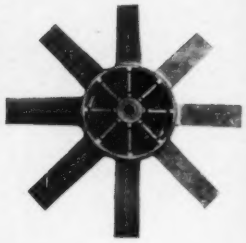
Interior of the reactor vessel recently constructed for the first Swedish nuclear power reactor. Pressure vessel design in Sweden is discussed in a special article. PAGE 479

Prof. K. Schoenemann, Head of the Darmstadt Institute of Chemical Technology, describes the application of modern chemical engineering techniques to Raschig's phenol synthesis and furfural production from xylose. PAGE 482



A new type of mixing head consisting of tubes placed on the periphery of a circular plate. A review of recent developments in the unit operation of mixing is compiled by G. J. Jameson. PAGE 489





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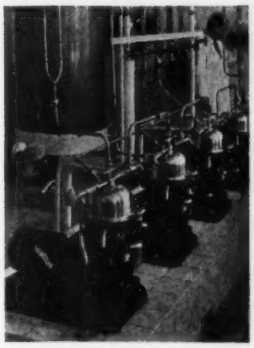
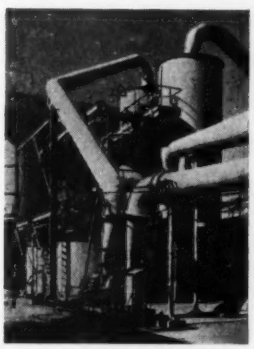


A series of centrifuges are used in this pilot-scale, counter-current extraction plant. The Unit Operations Review surveys new developments in centrifuging PAGE 545

Neoprene made by Du Pont in Maydown, Londonderry. Northern Ireland's chemical industry has expanded considerably during the last few years. This is discussed in a special article PAGE 540



Sulphuric acid plant at an Australian refinery protected throughout with epoxide resin paints. The importance of these paints for plant protection forms part of a special feature on corrosion PAGE 530

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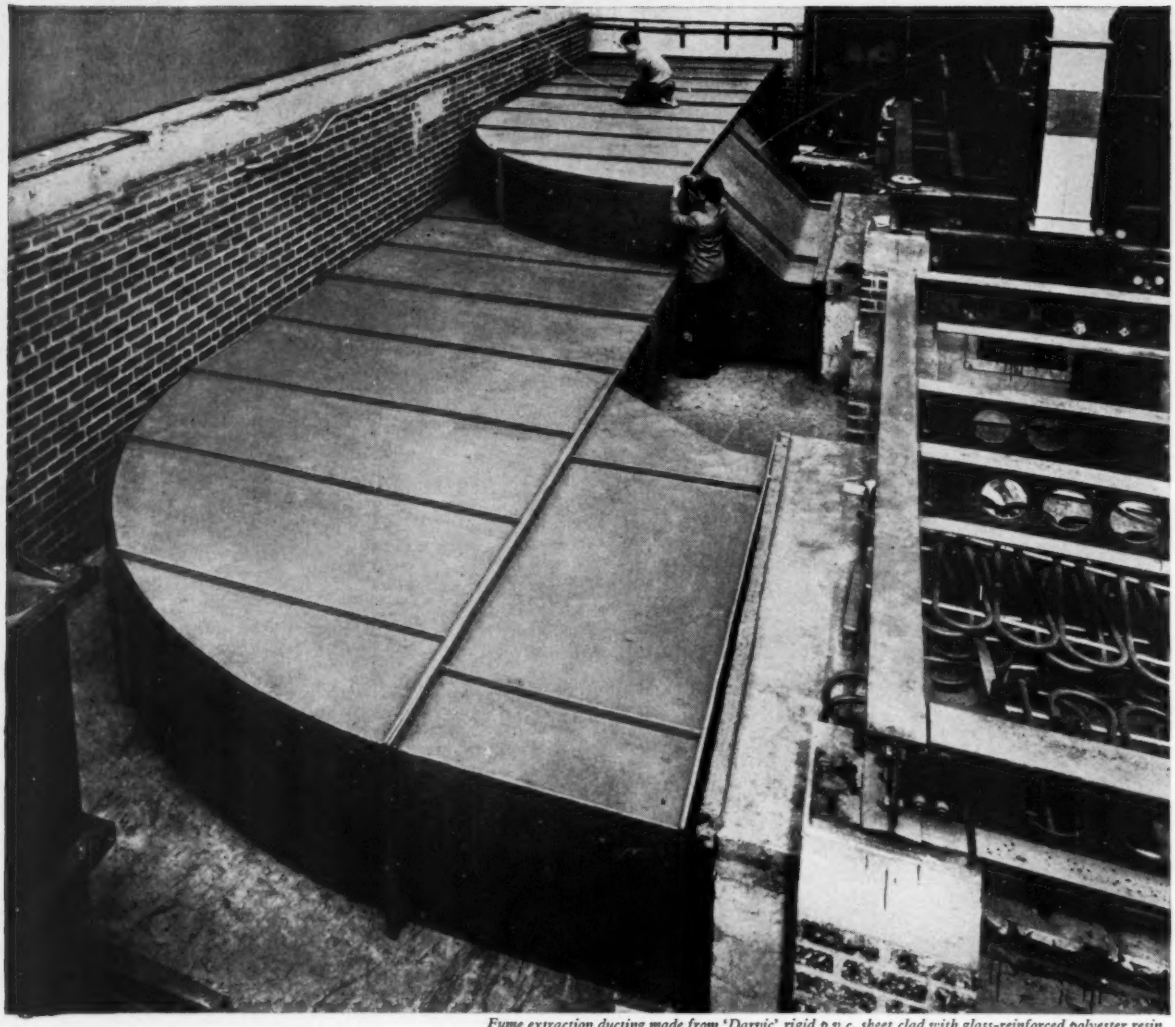

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CPE Comments and Topics

Wanted—a fuel policy

AMIDST the welter of conflicting interests it is hard to perceive even the glimmering of a co-ordinated national fuel policy arising from anywhere. This state of affairs, deplorable as it has become to all involved with the development of national fuel resources, is on the face of it quite incomprehensible. Of the three primary fuel-producing industries, the National Coal Board and the Atomic Energy Authority are nationally owned; whilst the Government has controlling interests in the petroleum industry. In addition the two largest consumers of primary fuel, the Gas Council and the Central Electricity Generating Board, are also nationally owned.

It would seem therefore that, given this state of affairs, all that any Ministry of Power would have to do would be to co-ordinate fuel policy 'at the summit' in the interests of the community. Rather than lay down a policy from the summit, however, we are subjected to more and more short-term decisions taken to placate the immediate interests of any given section of the fuel industry at any given time. The sum total of such *ad hoc* decisions has led to a state of affairs which is already bordering on the ridiculous.

Every reasonably informed person is aware of the dilemma now facing Mr. Robens, as the new chairman of the N.C.B. A case made out for preferential use of coal will more often than not meet with traditional sympathy even if it does not merit further consideration. Nuclear power likewise is a favourite Benjamin who, whilst not having come up to the expectations of his old father, is still a symbol of the 21st century but a bit too costly for nations that have to exist on 20th century incomes. This leaves petroleum which is becoming ever cheaper and plentiful, but, and this is the major drawback, has to be imported from 'doubtful' territories. How then are we to make our choice: with our heads or our hearts?

The answer so far has been with both. Vaguely expressed Government statements on fuel policy leave us with no clear picture other than that the race between the contenders for the 'fuel stakes' will go on much as before; with the weakest contender dropping out eventually. This is certainly the most wasteful way of doing anything and in the long run will damage the whole economic structure of this country—without bringing nearer the day when we can boast of a fuel policy.

Recently a start was made in the right direction by the Wilson Committee who examined the status of the coal industry with special reference to production of chemicals and gas. It is regrettable that no official action has as yet been taken by the Ministry of Power as a result of the committee's recommendations. The Gas Council, most closely involved in the future of coal, is making its own long-term arrangements to be based (and quite sensibly) on complete coal gasification by the Lurgi process and enrichment of this low calorific gas with methane or other liquefied petroleum gases.

The Central Electricity Generating Board has a more difficult path to follow since it cannot commission generating stations on economic merit alone. A mill-stone has been tied round its neck in the form of a limited number of gas-cooled graphite-moderated power stations which, in the opinion of many objective experts, are already obsolete as soon as they leave the drawing board. Yet this expensive road is felt to be the only path to salvation in the form of the advanced gas-cooled reactor and the high-temperature gas-cooled reactor. Such optimism would seem more credible if the C.E.G.B. were allowed, nay encouraged, to commission new designs for nuclear power stations, thus giving the contractors a sense of adventurous purpose which they have been lacking for so long.

A certain amount of team spirit infused into the whole structure of the fuel industry would doubtless pay long-term dividends. It is not suggested by anybody that one single industry must be sacrificed to ensure the survival of the rest; but it would help considerably if, to begin with, the chairmen of the nationalised fuel bodies would try to place their own industry within the framework of a co-ordinated national fuel policy. Only so can this curious state of affairs be resolved—and unless it is resolved the whole future of this country as an industrial power must remain at stake.

Synthesis gas manufacture

INCREASING interest in synthesis gas—the mixture of hydrogen and carbon monoxide that can be used for direct synthesis of hydrocarbons and methanol—is shown by the many processes for this reaction which are at present developed and licensed all over the world. The Wilson report, which we discussed in our October issue, dealt with the economics of synthesis gas produced by the water-gas reaction. This process was found to be uneconomical for British requirements.

A more recent method of producing synthesis gas is by partial oxidation of hydrocarbon fuels, a reaction developed by the Texaco Development Corporation and described by Du Bois Eastman in *Chemical Age of India*, 1960, **2** (11). The process comprises a feed system delivering precisely controlled quantities of fuel, oxygen and other reactants into a refractory-lined reactor where the fuel is burned to produce hydrogen and carbon monoxide, and a cooling system which recovers the sensible heat in the reactor effluent gases. It is convenient to consider the partial oxidation

reaction as a two-stage process consisting of a primary exothermic flame zone where free oxygen reacts with part of the fuel (for instance, methane) as follows:

$$4CH_4 + 2O_2 = 3CH_4 + CO_2 + 2H_2O \ldots\ldots \quad (1)$$

and a secondary endothermic zone where this carbon dioxide and water vapour react with the balance of the fuel to provide hydrogen and carbon monoxide as follows:

$$CH_4 + CO_2 = 2CO + 2H_2 \ldots\ldots\ldots\ldots \quad (2)$$

$$2CH_4 + 2H_2O = 2CO + 6H_2 \ldots\ldots\ldots\ldots \quad (3)$$

Experimentally it has been found that the reaction of free oxygen with hydrocarbon is so complete that no free oxygen can be found in the products. Therefore, the volume and temperature of the reactor are dictated almost entirely by the relatively slow reactions (2) and (3), whilst the shape of the reactor is dictated by the necessity of effecting heat transfer between the exothermic and endothermic zones.

Typical performance data for a wide range of fuels ranging from natural gas to −11° A.P.I. coal tar are given by Eastman. Although the weight ratio of C : H for this series varies from 3.2-11.5, fuel efficiency and oxygen consumption remain essentially unchanged. For example, natural gas with a C : H composition of 73.4 : 22.76 yields a synthesis gas with an efficiency 83.8% and the amount of oxygen consumed is 255 cu.ft./M cu.ft. $H_2 + CO$. Coal tar with a −11.4° A.P.I. gravity and a C : H composition 88.1 : 5.7 yields a synthesis gas with an 86.4% efficiency and the amount of oxygen consumed is 259 cu.ft./M cu.ft. $H_2 + CO$. This demonstrates the versatility of the partial oxidation process especially when comparing it with the rather narrow range of fuels that must be used in other synthesis gas reactions.

Coated-particle nuclear fuel

A PROJECT to develop properties of coated nuclear fuel particles has been assigned to the Battelle Memorial Institute by the American Atomic Energy Commission. In the coated-particle process small grains of the fissionable nuclear fuel compound—comparable in size to common table salt—are coated individually with a dense, refractory material that will both protect the fuel from damage by chemical reaction at the high temperatures of the nuclear reactor and prevent escape of the troublesome radioactive by-products formed in the fuel by the fission process.

Both carbon and alumina coatings have worked well in early tests conducted at Battelle in work related to the 'pebble-bed' reactor concept. After coating, the fuel particles are evenly dispersed in a material such as graphite, which can be conveniently shaped into reactor fuel elements by mass production methods. Such a fuel appears particularly attractive for high-temperature operations because only ceramic materials are utilised. Good neutron economy can also be expected from coated particle fuel.

In contrast, fuel elements used at present are limited by temperature due to metallic cladding.

Chemical plant in Holland

THE Dutch chemical industry has been expanding at a phenomenal rate since the end of the war; before the war Holland's chemical exports totalled £9 million, in 1959 they were £150 million. Hand in hand with development of the chemical industry there has been a growth in the plant construction industry. Before 1939 the Dutch engineering industry specialised almost entirely in shipbuilding and specialised plant like sugar mills; hence there was relatively little experience in design and construction of chemical plant.

The stimulus for creating a chemical plant industry in Holland came partly as a result of the Royal Dutch Shell Group decision in 1946 to enlarge their refinery and order as much equipment as possible from local engineering industry. It was recently announced that a new organisation called Netherlands Apparatus for the Process Industry (N.A.P.I.) is now to be formed to provide closer co-ordination between the chemical process and plant industries. This organisation will be somewhat similar to the industrial research associations which are sponsored by both D.S.I.R. and industry in this country.

The sensible outlook of the Dutch chemical industry must be largely attributed to the sound basis for technology and engineering that exists in Holland nowadays. Schools like the Technical University at Delft are good examples of Holland's determination to forget her colonial past and concentrate on becoming technologically self-sufficient. Thus the ties between industrial and university research are very close; in fact, most university technology departments are lavishly endowed by the Dutch chemical industry which as a consequence is almost entirely staffed by Dutch-trained engineers and technologists. The establishment of N.A.P.I. is another proof that Holland is taking chemical plant design and construction as seriously as other chemical engineering problems.

Solar energy—vision and realisation

FOR centuries man has been obsessed with the possibility of harnessing solar energy for his own needs. The sun's rays are the most abundant source of energy available (except possibly during an English summer). Thus it has been estimated that the total solar energy distributed over the surface of the earth every day is bigger than all the sources of energy ever used by man since the dawn of civilisation! If only a small fraction of this abundant energy could be harnessed for power generation an enormous benefit would be entailed.

A new type of solar battery was recently demonstrated in London. More than 10,000 silicon cells were mounted in a 26-sq.ft. panel on the roof of a 1912 Baker Electric which was then driven at a speed of about 20 m.p.h. These cells are constructed by bonding together two thin layers of silicon. One layer *n* is rich in electrons and the other layer *p* is rich in holes (the atomic structure which remains

after migration of electrons); a gap of several molecules thickness separates these two layers. Sunlight energises the silicon so that electrons pass from the *n* to the *p* layer generating a current. The maximum potential difference available from a single cell is at present very small but by wiring together many cells a reasonable voltage may be obtained.

Dr. C. A. Escoffery, of the International Rectifier Corporation, who demonstrated the use of these cells, stated that at present their main application was to energise electronic measuring instruments in space satellites. On earth many applications requiring constant small voltages, such as flashing light indicators, walkie-talkie transmitters and internal telephones could be powered with such silicon cells. Further developments in this branch of semi-conductors will obviously be watched with keen interest—although at present, due to the exceedingly high production cost, they are hardly in a position to compete with the more conventional electric batteries.

Electrolysis of sulphates

IN view of the considerable world shortage of raw materials for sulphuric acid production, attempts have been made frequently to develop a process in which both caustic soda and sulphuric acid could be obtained by electrolysis of sulphates such as gypsum or Glauber's salt.

It is well known that an aqueous solution of sodium sulphate, if subjected to electrolysis in a diaphragm cell, undergoes a reaction yielding sulphuric acid at the anode and sodium hydroxide at the cathode. However, both hydrogen and hydroxyl ions have considerably greater mobilities than those due to the dissociation of sodium sulphate; as a result the caustic soda and sulphuric acid are obtained at a very low concentration and abound with impurities. In addition, hydrogen and hydroxyl ions start a certain process of neutralisation resulting in decreasing current density which diminishes the acid and alkali concentration in relation to that of sodium sulphate. At a certain critical point, the rate of neutralisation equals the rate of acid and alkali production and the electrolytic current inside the cell begins to decompose water and not sodium sulphate.

Recently, K. Kerti, a Hungarian chemical engineer, developed an electrolytic process which overcomes all these shortcomings. It provides for acid and alkali concentrations to be largely dependent on current efficiency and not to be conditional on sodium sulphate concentration. The cell was designed by Kerti in such a way that hydrogen and hydroxyl ions are not able to act as current conductors whereas sulphate ions can move freely from the alkali to the acid compartment. Experimental evidence has shown that this method can decompose sodium sulphate into about 60% sodium hydroxide and 40% sulphuric acid with a current yield of at least 90%. It is hoped to apply this method not only to large-scale electrolysis of sodium sulphate but for recovery of metals such as nickel, cadmium, cobalt, iron and zinc, as most of these metallic ores are soluble in sulphuric acid.

Oil equipment industry

IT is reassuring to hear that the oil equipment manufacturing industry is in a very healthy position. This was stated recently by Mr. J. M. Storey, chairman of the Council of British Manufacturers of Petroleum Equipment. The remarkable expansion of this industry since the war can be clearly seen when it is recalled that before the war refinery plant, rockbits and geophysical survey instruments had to be imported from the U.S. During and after the war it was vital for this country to become less dependent on dollar sources and the oil companies readily co-operated with those manufacturing firms who were enterprising enough to embark on a new venture.

Over the first half of 1960, U.K. manufacturers received orders for equipment and materials to a value of more than £60 million. A typical example of orders received recently is an order for the supply of valve control equipment for use in the Soviet pipeline constructed across Eastern Europe. Other large orders for all kinds of equipment have come from South America and from non-British companies operating in other major oil-producing regions. Thus the total values of orders placed in the U.K. by the oil industry may well exceed £150 million during 1960. The present world oil supply position naturally raises the thought that in the immediate future, requirements of new equipment may tend to fall below past levels. However, the ever-rising oil consumption necessitates constant additions to the oil industry's facilities and as far as the future is concerned oil equipment makers can look forward to consistently large orders.

Thermal decomposition of coal

IT has been known for several years that the amount of smoke produced when burning briquettes, prepared from low-rank coal, could be reduced to negligible amounts by incorporating about 35% activated charcoal in the briquettes. In the 1959 annual report of the British Coal Utilisation Research Association a mechanism was proposed to interpret these observations which involve transient adsorption of the complex products of carbonisation followed by their decomposition and release as simple molecules which burn smokelessly.

Mixtures of coal and activated charcoal, when heated in a slow stream of nitrogen to about 600°C., gave rise to a colourless liquid which could be condensed in cooled traps. On analysis this 'oil' was found to consist of simple organic compounds such as benzene and toluene; combined yields of these two compounds, up to 0.7% of the dry coal weight from a particular low-rank coal, were greatest when the charcoal overlay was maintained at 450°C. These yields are substantially higher than those obtained from normal low-temperature carbonisation of the same coal (0.1%) and roughly equal to yields obtained in complex mixtures resulting from high-temperature carbonisation. It was deduced from weight balances for the system that a material consisting mainly of carbon was deposited in the charcoal.

The yield and composition of the products have been shown to be controlled largely by the amount of internal surface of charcoal accessible to volatile material emitted by the coal. In selecting a charcoal overlay, a balance must be struck between the need for wide capillaries to permit ready entry of the vapour molecules into the structure and for narrow capillaries to assist in retaining the adsorbed vapour as the temperature rises. To obtain best results, the total amount of surface accessible to dibutyl phthalate (an appropriate and convenient test substance) in the charcoal overlay should exceed 50 sq.in./g. of coal. It was found that many different carbonaceous adsorbents may be used (including cokes and chars), but a highly activated adsorbent (with an area of approximately 200 sq.in./g. accessible to dibutyl phthalate) appears to be essential if its weight is not to exceed that of the coal itself.

Industrialisation and effluent control

THE dawn of the industrial revolution in this country was a turning point in the economic history of this country. Although we can now prove to the world that Britain was the first country to realise the necessity of transforming herself from an agricultural into an industrial community, the birth pangs of early industrialisation have left scars up and down the countryside which will remain with us for the rest of time.

The first legislation to curb pollution of the countryside by indiscriminate discharge of acids and alkalis was the Alkali Act of 1863. The Leblanc process for manufacture of soda, adopted in this country soon after the Napoleonic wars, at first discharged all by-product hydrogen chloride gas into the atmosphere. As a result of the Alkali Act the Gossage tower to condense this gas was adopted, thus offering a simple method of disposing this hydrochloric acid by running it into streams rather than into the atmosphere! Even so, many manufacturers condemned this Act as unwarranted interference with private business.

In the second half of the 20th century we have become a little less selfish—industrial pollution is now considered a national problem and both industry and the government make sensible provisions to combat it as far as possible. The Water Pollution Research Laboratory, a D.S.I.R. establishment, has been in existence for many years dealing with the best methods of treating effluents prior to their discharge into sewers, and examining the effect of sewage discharge into rivers and streams. As regards prevention of water pollution, this country has probably the finest record in the whole world. (Dr. B. A. Southgate, Director of the W.P.R.L., is co-author of an article on treating detergent-containing effluents in this issue's special feature on industrial effluents.) The wholly different problem of safe disposal of radioactive wastes is being tackled systematically and efficiently by the U.K.A.E.A. (R. H. Burns, a leading authority on this subject, has also contributed to this feature).

In the under-developed countries of Africa and Asia the folly of too rapid a rate of industrialisation, with primitive or non-existent effluent treatment facilities, soon brings in its wake a gradual silting-up of rivers and streams—this was recently found in Brazil, for example. Surely here is a field where the United Nations could usefully help. An international agency for sewage treatment and effluent control should deal with this growing problem at an international level and advise all the younger states on how best to combine a high rate of industrialisation with an optimum effluent disposal system.

How to make friends

THE prestige value of physicists and especially those employed by the U.K.A.E.A. is slipping fast—so Ritchie Calder warned us in the November issue of the *Bulletin of the Atomic Scientists*. According to Calder the romantic days of atomic energy are over in this country to such an extent that ' you can't even date a girl nowadays by saying you are at Harwell '. This statement had us seriously worried. We had always been brought up to believe that just beneath Olympus where the gods dwell is the permanent site of the atomic supermen, Harwell-near-heaven geographically speaking. Surely those demons of creation and destruction must evermore be deserving of our unbounded adulation and esteem!

Consequently we departed that same evening to disprove this irresponsible theory. Having been invited to a party we determined to test the reaction of the opposite sex to anything faintly radioactive. The first girl we met, pony tail and pseudo-Chelsea, asked us how we made our living. ' Top secret ', we replied, ' we are not allowed to divulge, but confidentially we work in a little place in the country called Harwell—you know? ' ' Of course ', replied Miss Know-All, ' you must be something scientific, you're in the country working on foot-and-mouth disease, aren't you? ' We terminated the conversation and concentrated our whole attention on something blonde, attired in a creation which, if it didn't exactly come from Dior, certainly deserved to do so. We turned on all our charm and explained that much as we would have liked to reveal our exact profession and place of work we were prevented from so doing by the Official Secrets Act. We could, however, hint that our work was sometimes radioactive. ' Have you ever thought ', countered Miss Genius, ' of going on " What's My Line " ? They pay 10 guineas for an appearance and would have a hard time guessing '.

Disgusted at this, we turned to the bar for consolation and asked the barman whether he knew what time was the last train for Harwell, which we didn't want to miss. ' Never heard of the place ', said he, ' I shouldn't be surprised if it is the name of one of them dogs the Russians have sent into space; don't you think it a shame that them scientists should send our poor dumb cousins into space? ' We agreed and wished wholeheartedly that the present assemblage might have been transferred to outer space instead.

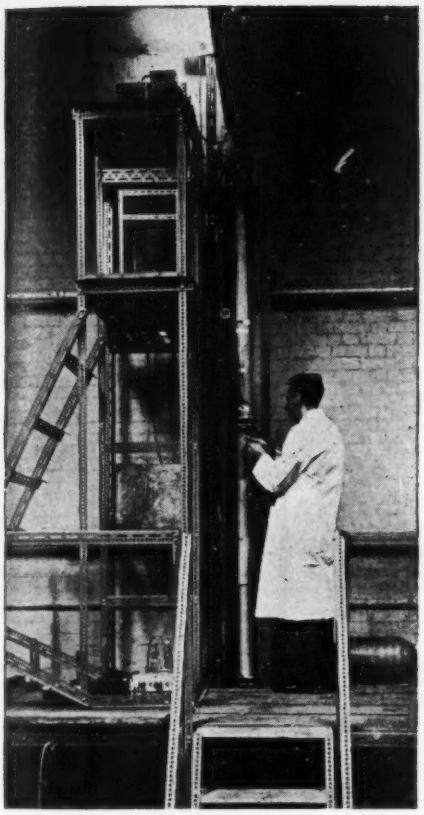


Fig. 2. Upper portion of 15-ft. column used for experiments on the effect of detergents on the rate of absorption of oxygen from air bubbles

The Luton Experiment

By B. A. Southgate,* C.B.E., D.Sc., Ph.D., F.R.I.C.
and G. E. Eden,* B.Sc., F.R.I.C.

The Jephcott Committee was appointed by the Ministry of Housing and Local Government to investigate the increasing difficulties experienced in treating sewage containing household detergents. As a result it was recommended that manufacturers should try to produce detergents which could more readily decompose during sewage treatment; a new form of surface-active agent, referred to as biologically 'soft', was developed eventually. This article describes experiments carried out at the Water Pollution Research Laboratory in testing this new material. Subsequent field trials of detergents containing this material in the Luton area are also reported and their success is discussed.

POPULAR accounts of the effects brought about by the introduction of synthetic detergent powders in this country have dealt mainly with the occurrence of foam on rivers. This is certainly the most obvious sign of their presence, but in fact they have caused a variety of difficulties in the treatment of sewage, some of which have taken some years of research to unravel and, apart from having caused foaming, they have had other unexpected adverse effects on the quality of river-water.

The treatment of domestic sewage is by now a well-known art and, with a properly designed and operated sewage works, it is always possible to produce an effluent of good quality. Where difficulties have arisen they have usually been due to the discharge to the sewers of industrial wastes which have interfered with the processes of purification and so have led to a deterioration in the quality of the effluent.

Trade wastes may cause a wide variety of difficulties at a sewage works but perhaps the most usual are interference with the separation of sludge in primary sedimentation tanks, or with the subsequent digestion and drying of the sludge, or with the aerobic biological processes by which the bulk of the organic matter in the settled sewage is removed. Where the efficiency of biological treatment has been reduced by the presence of inhibitory substances, the sewage effluent finally discharged may well contain much more oxidisable matter than would be obtained from the treatment of purely domestic sewage, and thus it will cause a greater depletion of dissolved oxygen in the receiving stream. In addition some toxic constituents of trade effluents are not wholly removed at a sewage works and the effluent discharged may then contain so high a concentration of them that the receiving stream itself becomes toxic.

Dissolved oxygen

When a sewage effluent is discharged to a river, one important matter is the effect which it has on the level of dissolved oxygen in the river-water. This level is particularly important if the river contains fish, which will be asphyxiated if the concentration of dissolved oxygen falls below a certain limiting value. A fishery will, of course, be damaged also if sufficiently large amounts of toxic materials are discharged, and the toxicity of a given concentration of a poison is normally greater the lower the concentration of dissolved oxygen. Polluting substances may have many other effects on streams—for example, they may cause large changes in the abundance and distribution of species of plants and invertebrate animals—but from an economic point of view their effect is likely to be most serious when a river is used below a point of pollution as a source of domestic water supply. In this case the presence of physiologically harmful substances may ren-

**Water Pollution Research Laboratory.*

der the water unsuitable for treatment and distribution to the public.

There is wide experience of these various kinds of difficulties which have been caused by the discharge of industrial effluents to sewers and it is now common practice for manufacturers to pre-treat particularly obnoxious wastes before they are accepted by a local authority. With the introduction of synthetic detergents, however, many of the consequences which have been described have been brought about by the presence of a material used mainly in the household. Here there is, of course, no possibility of pre-treatment and, as will be seen, the only practicable solution of the problem has been to modify the composition of the detergent itself. Before describing the results of this change, however, a brief account of the various difficulties caused by the types of detergent first put on the market may be of interest.

The first noticeable result of the presence of detergents in sewage occurred in 1949 when large quantities of foam appeared at sewage-treatment plants. In treating sewage it is first passed through primary sedimentation tanks, where sludge is removed, and the supernatant liquid is then purified by an aerobic biological process.

This process may be biological filtration, in which the liquid is passed downwards through beds of stone, clinker, or other hard medium on which an active film of micro-organisms develops, or it may be treated by the activated-sludge process in which the liquid is aerated in contact with a bacterial floc; something like half the sewage in Great Britain is treated by the latter process which is used particularly at the larger works. Although most sewage works of both types reported the presence of some foam, the worst conditions occurred, as might be expected, in the aeration stage of the activated-sludge process, where at times layers of foam several feet in thickness accumulated. This greatly interfered with maintenance and operation of the plant and in some districts caused a nuisance when it was blown away by the wind. Various methods of suppressing it were tried, the one now most usually adopted being to add a defoamant to the liquid in the aeration tanks; this, though expensive, is reasonably successful.

Decreasing purification efficiency

A more serious matter, however, was that it became noticeable, particularly at sewage works using the activated-sludge process, that the efficiency of purification was deteriorating. A great deal of research was thereupon started to ascertain the extent of this deterioration and its cause. Although there is still some doubt about several of the factors involved, it is now certain that in some circumstances the presence of synthetic detergents in sewage can bring about a substantial reduction in the efficiency of a works. The constituent of the detergent mainly responsible for this is alkyl benzene sulphonate, which is the principal surface-active component of the mixture.

Unlike most substances in trade wastes which interfere with sewage treatment, alkyl benzene sulphonate does not appear to be markedly inhibitory to the bacteria responsible for the purification of sewage, but acts rather by reducing the rate at which, in given circumstances, gaseous oxygen will dissolve in water. This explains why it causes less deterioration in the performance of percolating filters than of the activated-sludge process. Filters, as used in this country, are not normally ventilated by forced draught; they have ventilation channels at their base and are open to the air at the top, and the oxygen reaching the interior of the beds of medium circulates as a result of small differences in temperature between the filter and the outside air. Nevertheless, with a filter in good condition—that is to say not choked by deposits or excessive biological growths—there is usually a quite adequate supply of oxygen to the liquid being treated; in spite of the rapid oxidation which occurs during treatment, the concentration of oxygen in solution in the liquid usually increases markedly as it flows downward through the bed of filtering medium. This, no doubt, is because the liquid flows through the bed as a very thin film, thus having a large ratio of area to volume.

In the activated-sludge process several methods of aeration are used, one of the commonest being to pass air through porous diffusers placed on the bottom of the aeration tanks—usually some 12 ft. deep—the air then rising through the liquid in the form of fine bubbles. The effect of alkyl benzene sulphonates on this process was studied in pilot plant at the Water Pollution Research Laboratory. Typical mixtures of settled sewage and activated sludge, in vessels 15 ft. deep, were aerated by measured flows of air, the gas emerging at the surface being collected and passed to a continuous oxygen recorder (Figs. 2 and 3); at the same time the concentration of oxygen in solution in the liquid was determined periodically. These experiments showed clearly that, when the alkyl benzene sulphonate was added, the proportion of oxygen in the gas leaving the system increased, less having dissolved as the bubbles of gas passed upwards through the liquid. Consequently the concentration of oxygen in solution fell.

In spite of the fact that in this process air is supplied to the system from compressors, the concentration of oxygen in the liquid in an aeration tank is commonly lower than it is in the thin films of liquid passing downwards through a percolating filter; consequently if the level is further

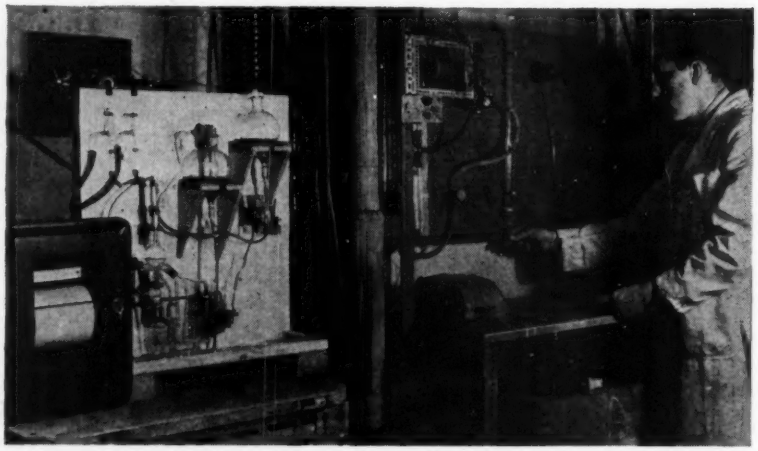


Fig. 3. Lower part of column shown in Fig. 2. Apparatus for recording the concentration of oxygen in the air issuing from the top of the column is seen on the left

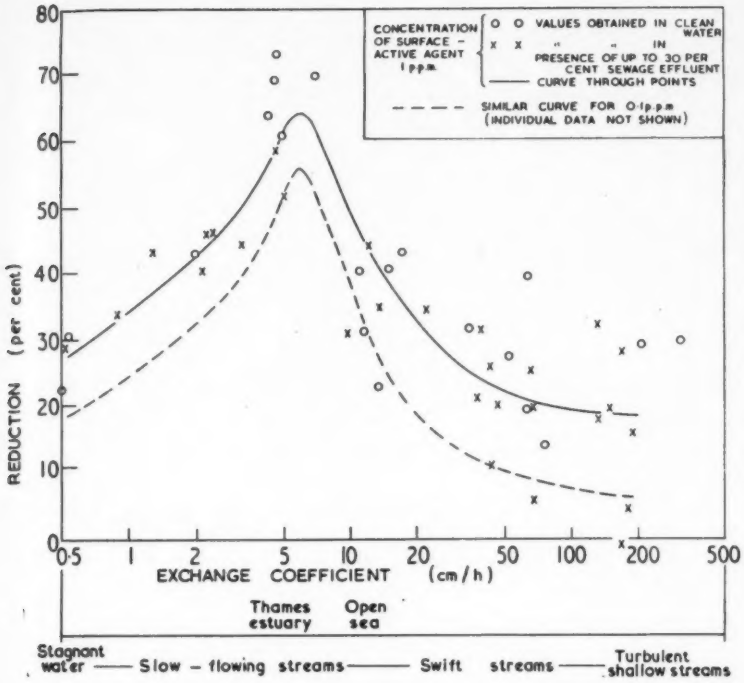


Fig. 1. Effect of a surface-active agent (alkyl benzene sulphonate) on rate of aeration of flowing water

reduced by the presence of detergents, it may fall to so low a value as to reduce the bacterial activity on which the process of purification depends. The first indication of this is likely to be a reduction in the proportion of the ammonia in the settled sewage which is oxidised to nitrate. This reduction was found both in the laboratory experiments and at those activated-sludge plants where interference with the purification process by detergents had been reported.

There is still much which is unknown about the precise effects of detergents on sewage treatment—for example, their influence on mechanical forms of aeration at activated-sludge plants has not been properly explored—but it is quite clear that they have, in many instances, caused a serious deterioration in performance.

Detergent concentration in sewage

From a knowledge of the quantities of detergent sold, and of the approximate volume of sewage in Great Britain, it was calculated that the average concentration of surface-active material in the sewage would be about 14 p.p.m. Some of this material is removed by adsorption on sludge separated in the primary sedimentation tanks at sewage works, but a large proportion of it (perhaps some 12 p.p.m.) passes forward to the aerobic biological process of treatment.

When detergents were first introduced into this country on a commercial scale much of the material contained secondary alkyl sulphates as their surface-active agent and it is known that these were comparatively easily destroyed by bacterial action at sewage works. The alkyl benzene sulphonate which is the surface-active component of the more recent powdered synthetic detergents, however, is comparatively resistant to bacterial attack and some of it escapes destruction in passing through a percolating filter or through the aeration stage of the activated-sludge process; consequently from about 1949 onwards sewage effluents began to contain appreciable quantities of the surface-active matter. It was thus important to determine what effect these substances would have in streams to which sewage effluents are discharged.

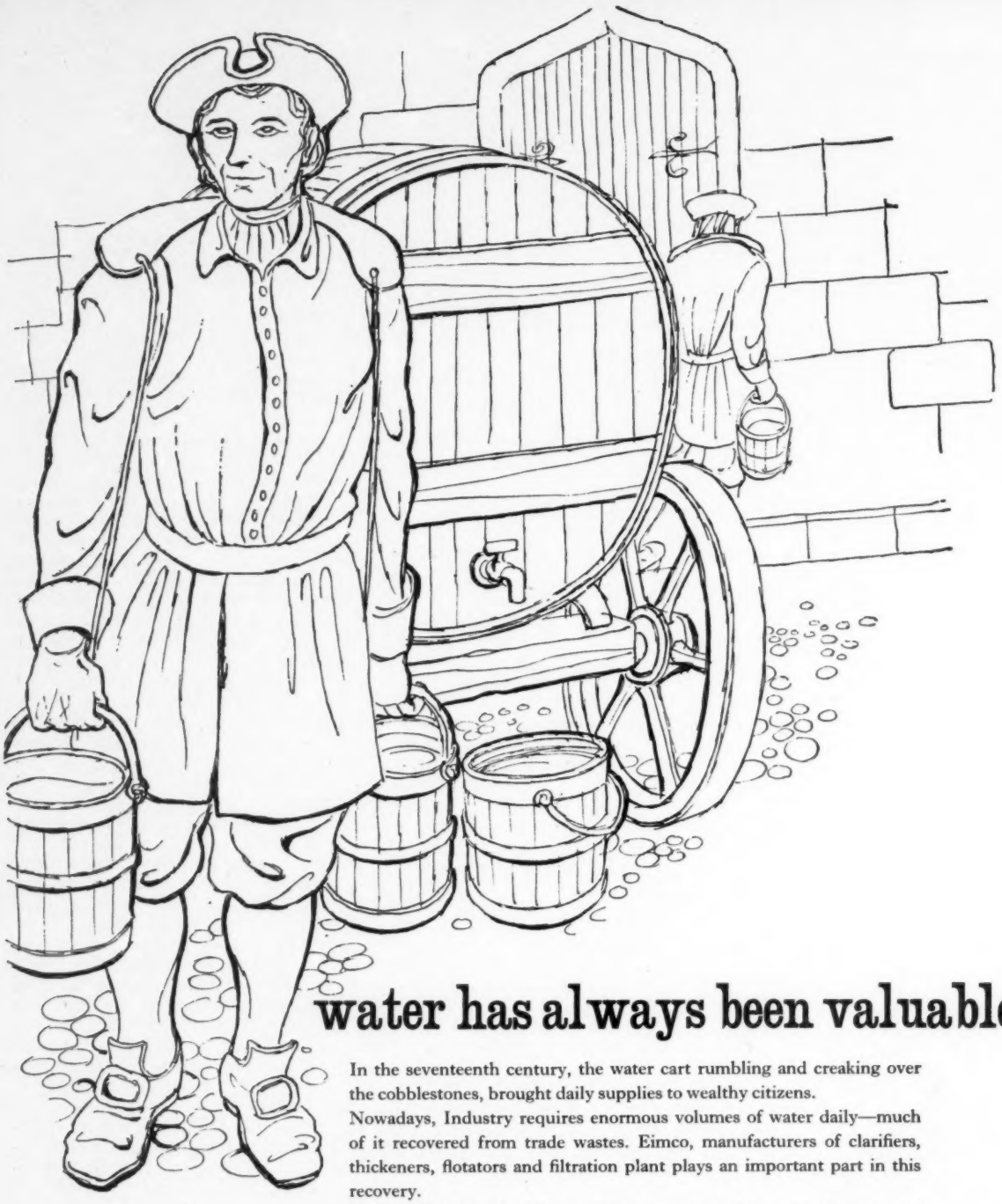
Effect on streams

It was soon apparent from laboratory experiments and from work in the field that even very small concentrations of alkyl benzene sulphonate in a river might reduce considerably the rate at which the water, when partly de-oxygenated, would absorb oxygen from the air. Thus, in a stream below the point of discharge of a sewage effluent, the concentration of dissolved oxygen would fall to a lower value if the effluent contained surface-active material than if it did not.

In attempting to predict what the effect of an effluent on a stream will be, the rate at which the stream will absorb oxygen from the air is of great importance, and much experimental work has been done to determine the precise effect of the presence of surface-active material under different conditions. The story which has emerged is quite complex. In water which is moving only slowly, and thus is taking up oxygen from the air at a low rate, the effect of adding alkyl benzene sulphonate is small. Similarly in water which is very turbulent and thus absorbing oxygen at a high rate, the effect again is small. Between these extremes the effect increases to a maximum, where the presence of 1 p.p.m. of the surface-active material will reduce the rate of absorption of oxygen by the partly de-aerated water by over 60% of its normal value (Fig. 1). Unfortunately, the degree of turbulence at which this maximum occurs is about the same as that found in typical British rivers flowing through lowland country. Thus the presence of detergent residues in sewage effluents has a considerable influence on the oxygen balance of polluted streams.

A fall in the level of dissolved oxygen in a river will, of course, be important to a fishery if the river supports one. It was at first thought that in addition detergents might have a directly toxic action on fish. This was, in fact, found to be the case with packaged detergents, though the toxicity was low. For example, alkyl benzene sulphonate in a concentration of 3 p.p.m. will kill, on the average, half a batch of trout exposed to it during a period of 12 weeks. Curiously, however, it was found that the toxicity to fish of alkyl benzene sulphonate was reduced by passage through a sewage-treatment plant (a given concentration in a sewage effluent being compared with the same concentration of the untreated material, both determined by the standard method of analysis of Longwell and Maniece[1]).

Presumably, passage through the treatment plant causes a chemical change in the molecule which reduces its toxicity, or removes from the mixture of closely related substances forming the commercial alkyl benzene sulphonate those components having the greatest toxicity. It was con-



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cluded that detergent residues, in the concentrations in which they occur in British rivers, were unlikely to have any serious direct effect on fish.

Particularly in lowland districts, much of the water taken from surface sources for public supply (after, of course, rigorous treatment at a water works) is from rivers which have passed through populated districts, and to which therefore sewage effluents have been discharged. A water intake will normally be at some distance below the last point of entry of a sewage effluent and in flowing to the water intake the concentration of detergent in the water will fall, partly because there is likely to be dilution from unpolluted tributaries, and partly because the processes of bacterial destruction of the detergent, begun in the sewage works, will be continued in the stream, though at a lower rate.

Jephcott Committee

Some four or five years ago the effects of the introduction of detergent on the public health services were considered in detail by a committee set up by the Ministry of Housing and Local Government under the chairmanship of Sir Harry Jephcott[2] and this committee collected much information from water authorities on the concentrations of surface-active materials in their raw water supplies. Although most of the water taken from rivers to which sewage effluents had been discharged contained some surface-active material, the concentrations were usually quite low, mostly no higher than 0.5 p.p.m., though in a few instances as high as 1 p.p.m.

Concentrations of this magnitude were not known to have any physiologically harmful effect on man but nevertheless the committee expressed concern lest the amount present should increase (much higher concentrations have been reported, for example, in a few American water supplies) and they made it clear that a serious attempt should be made to reduce the damage and inconvenience which, in various ways, the public health services were suffering from the still increasing use of detergents in the household.

It may be mentioned that one of the suggestions made—and this is sometimes put forward when an industrial effluent is involved—was that the situation should be met by altering in some way the processes of treatment at sewage works. It was proposed, for example, that research might be put in hand to isolate or develop strains of bacteria which would be particularly efficient in destroying alkyl benzene sulphonates. About this it can only be said that it is quite impracticable to sterilise sewage before it is treated; the bacterial population present in a plant is that which will flourish in the particular conditions of treatment and little can be done to modify it. In fact, if it were possible to modify the metabolic characteristics of bacteria to make them more effective the modified strains would have been expected to have developed naturally during the several years that detergents had been present in the sewage which was being treated.

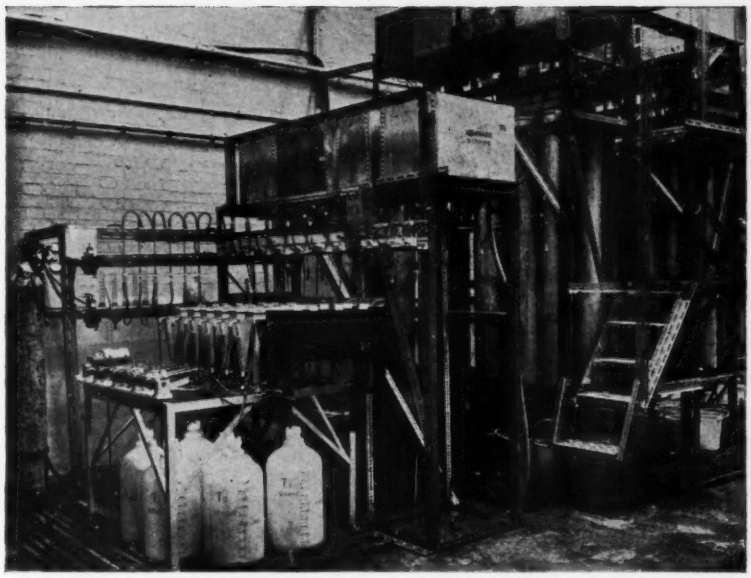

Fig. 4. Apparatus used in laboratory experiments on the breakdown of detergents during sewage treatment. Activated-sludge units on the left, percolating filters on the right

Again, it was shown that at some works foaming on aeration tanks of activated-sludge plants was reduced when the concentration of activated sludge maintained was increased. This concentration, however, is chosen and maintained to give the most effective treatment of the sewage and it cannot usually be altered very much without causing a serious deterioration in the quality of the effluent. It became clear that this method of approach would certainly not solve the problem and the committee therefore recommended that manufacturers should try to produce detergents which would be more readily decomposed by the processes of sewage treatment in general use in this country.

'Dobane' JN

Shortly after these recommendations were published the manufacturers made available experimental quantities of a new form of alkyl benzene sulphonate which, in screening tests, they had found to be more readily destroyed biologically than the material previously used. For convenience the new material (sodium *Dobane JN* sulphonate) is referred to as biologically 'soft' in contrast to the original material (sodium *Dobane PT* sulphonate) which was biologically 'hard'. The Standing Technical Committee on Synthetic Detergents, which had succeeded the Jephcott Committee, arranged for the new material to be submitted to various laboratories for preliminary testing.

In these tests the new material, added to river water and incubated in the presence of oxygen for several days, was fairly readily destroyed; in a typical test some 12% remained after 16 days as compared with 80% of the old. The Water Pollution Research Laboratory, at the request of the committee, then undertook further testing to compare the behaviour of the 'hard' and 'soft' materials in sewage-treatment processes in the laboratory (Fig. 4). These showed that in an efficient sewage-treatment process some 94% of the new material was removed as compared with 67% of the old. It is interesting that in both cases a period of acclimatisation of about 10 weeks was required after the introduction of the detergent before the degree of removal reached its maximum. This may well be an example of the type of modification

already referred to, in which the metabolism of a biological population becomes adapted to deal with a hitherto unencountered material.

Subsidiary experiments showed that the amount of foam produced when effluent from the treatment of sewage containing the new material was aerated under standard conditions was very small—indeed was indistinguishable from the amount produced by a completely detergent-free effluent. It was very much less than the amount produced from effluent containing residues of the 'hard' detergent. This effect was entirely due to the low concentration of residual 'soft' material, as it was found that equal concentrations of residues from the two types of surface-active material produced equal amounts of foam under standard conditions.

It has since been found that 'hard' and 'soft' detergents which have not passed through sewage-treatment processes will, at similar concentrations, yield different amounts of foam. Thus the amount of foam produced during the treatment of sewage containing 'soft' detergent by the activated-sludge process may be considerably greater than the amount produced at the same works when a similar concentration of 'hard' detergent was present.

As a consequence of the almost complete removal of the new material in sewage-treatment processes the detrimental effect of detergent on the efficiency of sewage treatment was much reduced and the final effluent was not toxic to fish.

Luton experiment

On completion of the original laboratory tests the manufacturers expressed their willingness to produce the new detergent in much larger quantities so that a test of the new material could be undertaken on a full scale. The committee decided to accept this offer and arrangements were made for the large-scale demonstration which has since become known as the Luton experiment. Luton was chosen for several reasons: it is a compact and comparatively isolated community; it has a highly efficient sewage-treatment plant which discharges its final effluent into the River Lee, a source of part of the London drinking water supply; and it is conveniently situated for technical supervision of the experiment.

The design of the experiment was that the three manufacturers who control virtually the whole market in packaged synthetic detergents would make available special batches of material which would contain 'soft' in place of 'hard' alkyl benzene sulphonate but which would otherwise be identical with the materials normally on sale. These special batches of packaged detergent were supplied to Luton through the normal trade channels.

The substitution began in August 1958 and its progress was observed by the manufacturers, who made periodical checks of the materials on sale in the shops of Luton. Known stocks of 'hard' material were replaced by 'soft' to assist the process of changing over as far as possible. The changeover took considerably longer than had originally been expected, but by April 1960 over 99% of the products of the major manufacturers on sale in Luton consisted of the 'soft' material.

During this time regular measurements were made at the Luton sewage works to determine the effects of the changeover. Samples of settled sewage were examined (by infra-red spectroscopy) at the Laboratory of the Government Chemist to determine the ratio of 'soft' to 'hard' material in the sewage undergoing biological treatment at the works. This proportion rose to about 60% in the first year and to about 80% after two years. At the time of writing there remains an unexplained discrepancy between this proportion and the proportion of 'soft' material in the detergents on sale in the shops. This discrepancy is presumably due to the using up of stock of old material in homes, to the use of 'hard' materials in products not included in the experiment (for example, scouring powders), and to the introduction into the town of 'hard' detergent materials purchased elsewhere. Since August 1959 the production of the new material has been increased to such an extent that it is now distributed over a large proportion of the south of England. This development in itself should reduce considerably the amount of 'hard' material reaching Luton from the surrounding areas.

Reduction in weight discharged

Estimates have also been made of the weights of surface-active material appearing each day in sewage and in final effluent. These have indicated a reduction of about one-third in the weight of surface-active material in the settled sewage. This reduction is attributed to the decomposition of the new 'soft' material in the sewers, an unexpected but very satisfactory effect. The proportion of the remaining surface-active material removed in the subsequent biological treatment of sewage increased during the first year roughly in agreement with predictions based on laboratory results. During the second year, however, the proportion removed has remained constant. Nevertheless, the weight of surface-active material entering the river in the final effluent has continued to fall as a result of the decomposition in the sewers already mentioned; for example the weights discharged in the final effluent on Wednesdays were, in July 1958, 262 lb., in August 1959, 165 lb., and in August 1960, 83 lb. In confirmation of these observations, measurements by the Metropolitan Water Board of the concentration of surface-active material in the water of the River Lee, some 14 miles downstream, have shown a corresponding reduction.

Further reduction in the weight discharged may be expected if the proportion of 'soft' material in the Luton sewage continues to increase or if there is further acclimatisation of the biological treatment process at the works. It seems reasonably certain at the time of writing that the eventual reduction in the weight of surface-active material discharged to the river will be rather less than that predicted on the basis of the laboratory experiments. This is, perhaps, hardly surprising in view of the greater variation in operating conditions observed at the works. Moreover, the degree of removal at the Luton works, which is one of the most efficient in the country, is likely to be greater than that at most other works. There is a probability, therefore, that the final verdict on the Luton experiment will be that the new material, though an improvement on the old, is still not sufficiently 'soft' to provide a satisfactory solution to the problems raised by the introduction of the original synthetic detergents and which were outlined in the earlier part of the paper.

Acknowledgments

The experiments described in this paper were carried out under the supervision of the Standing Technical Committee on Synthetic Detergents.

The paper is published by permission of the Director of the Department of Scientific and Industrial Research.

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[1] Longwell and Maniece, *Analyst*, 1955, **80**, 167.

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Biological Oxidation of Phenolic Waste Liquor

By G. F. G. Clough*
B.Sc.(Eng.), A.M.I.Mech.E., A.M.I.E.E.

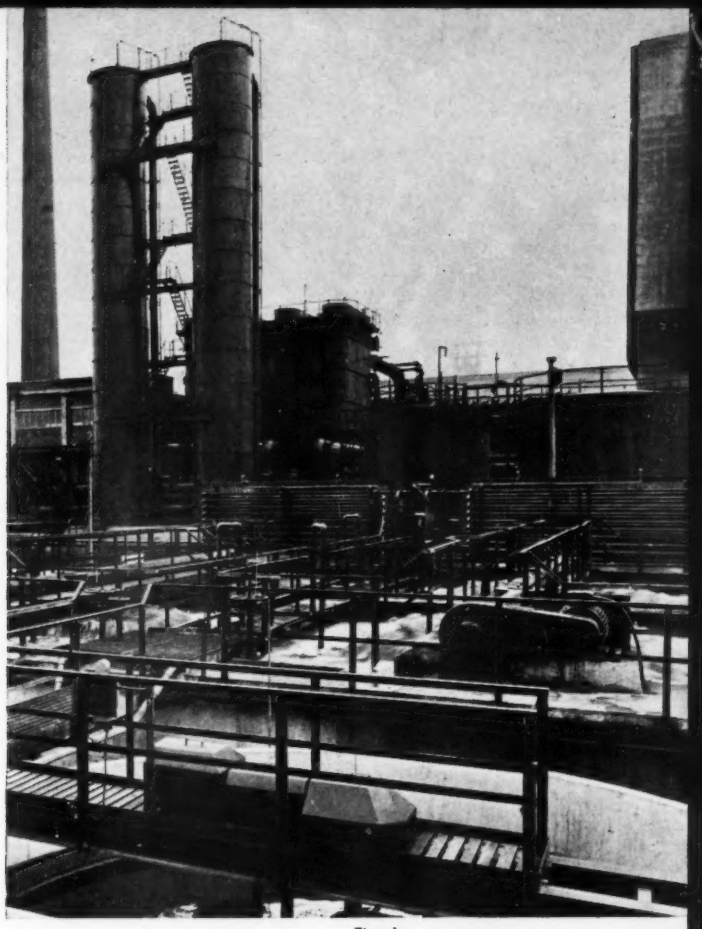

Fig. 1

There are many chemical processes which give rise to phenolic effluent. In the past these effluents have frequently been allowed to flow into the nearest watercourse thereby giving rise to pollution. This article describes a plant designed for the oxidation of phenolic waste liquor from an ammonia still, particularly stressing the economics of the problem. Any effluent amenable to bacteriological oxidation can be treated by a similar process provided optimum conditions are first determined in the laboratory.

THIS article describes a plant for the biological oxidation of a phenolic effluent installed in a large steelworks near Chester. The effluent is basically spent liquor from the ammonia still in the by-product plant, and it contains small amounts of various other minor effluents. A typical analysis is given in Table 1.

No distinctions have been made throughout the article between monohydric and polyhydric phenols, although in practice the latter are more difficult to oxidise. Where the term 'phenol' is used, it is assumed that it can be a mixture of monohydric and polyhydric although mainly monohydric phenols.

Before describing this plant, however, it is as well to consider briefly the necessity of installing such plants and the basis on which it is designed.

Table I. Composition of effluent

	Composition range, p.p.m.
Total phenols	600—800
Monohydric phenols ..	510—665
Polyhydric phenols ..	93—135
Thiocyanate and cyanide	100—185
Thiosulphate	110—120
Ammonia	730—870
Nitrite	Nil
Nitrate	Nil
*p*H value	8.5—9.7
O.A. (4h. permanganate)	1,450—1,745

There are many chemical processes which give rise to a phenolic effluent, the concentration of phenol usually being in the range of 500 to 10,000 p.p.m. In the past, these effluents have frequently been allowed to flow into the nearest watercourse, thereby giving rise to pollution. Although effluents of this type inhibit normal bacterial activity, they can be oxidised by certain strains.

In the case of effluents discharged to rivers, the phenols will be slowly oxidised, taking oxygen from the river water in the process and thus reducing that available for other forms of life. Fish may be poisoned by the presence of phenol, the amounts necessary varying with the species; as little as 6 p.p.m. may be lethal. Fish living in lower concentrations can become

*Simon-Carves Monsanto Effluent Advisory Service.

tainted and unsuitable for use as food. Where water is taken from the river for drinking purposes and subsequently chlorinated, chlorophenols may be formed which, even in very small concentrations, give rise to an objectionable taste.

Discharge to sewers

If the effluent is discharged into the public sewer, the inhibitory action of the phenol on the sewage organisms may be sufficient to upset the operation of the sewage works receiving the effluent. The extent to which this may occur will depend on the ratio of the quantity and concentration of the phenolic effluent to the capacity of the sewage works, *i.e.* the phenolic effluent handling capacity of a sewage works is limited.

It is apparent, therefore, that in many cases, the quantity of phenol in an effluent should be reduced before discharge. There are several ways in which this may be done.

Where a saleable product can be recovered, an extraction process may be the best solution. The more usual case, however, occurs where the concentration of phenol is too low to make extraction worth while and biological oxidation is then likely to be the best method of destruction. Under the conditions normally existing in the river, the action of the phenol oxidising bacteria is slow. The process can be speeded up by providing conditions suitable for optimum growth and activity of the bacteria. These conditions are an adequate supply of oxygen, a correct temperature range, the right *p*H value, adequate nutrients, suitable physical conditions and absence of inhibitory substances.

The design of the treatment plant is concerned with providing and maintaining these conditions at their optimum values. The methods used vary, but may be listed briefly as follows.

Oxygen supply

The oxygen required is obtained from the atmosphere and an air/liquid contacting system is therefore required. Those normally used include percolating filters in which the effluent flows downwards over some form of packing, while air flows upwards through the interstices. Diffused air systems in which compressed air is distributed by diffusers along the bottom of the tank may be used and also stirred sparged systems in which air is introduced beneath a rotating paddle. There are also surface aeration systems where the aeration is carried out at the surface of the liquid.

Each system has its own advantages and disadvantages and the system eventually chosen depends on the particular circumstances.

Temperature and *p*H

The temperature of the aeration system is best controlled to within about 5°. Operation outside the optimum temperature range leads to a reduction in efficiency, hence a reduction in the handling capacity of the plant. It is often possible to use waste heat for maintaining the temperature.

The *p*H of the effluent under treatment must be kept steady at the optimum value. Attention has to be paid to the change in *p*H during treatment arising from the activity of the bacteria.

Small concentrations of certain elements are essential for promoting maximum growth and activity of the bacteria.

Physical conditions

Some bacteria work best in the turbulence of an activated sludge system; some prefer the more static conditions existing in a filter bed. Thorough mixing is necessary in a sludge system, but the agitation should not be so vigorous that the sludge is broken up.

Inhibitory substances interfere with the normal action of the bacteria and may even kill them. A typical example is the inhibition of thiocyanate oxidising bacteria by a high concentration of phenol. In extreme cases, the bacteria may be killed off by the presence of excessive amounts of harmful substances, for example, certain metallic salts.

The necessary environmental conditions are established by investigation in the laboratory, and the plant is then designed to provide these conditions. To confirm the laboratory work on a larger scale, the installation of a pilot plant may be advisable before the main treatment plant is designed.

Pilot plant

A pilot plant was installed at Shotton. It consists of three stages, the first and third being sludge tank systems and the second stage percolating filters. The three stages were installed in order to carry out experimental work on the removal of thiocyanate, thiosulphate, cyanide and ammonia, in addition to the removal of phenol.

The phenol stage, which is the part relevant to the present article, consists of two activated sludge tanks each of 130-gal. capacity, followed by a settling tank. Each sludge tank is baffled and fitted with a stirrer and air sparge pipe to aerate the tank contents. Incoming effluent is fed to the first tank, passes over a weir into the second tank and finally to the settling tanks. Here the sludge is settled out and returned to the first aeration tank. The results obtained from the pilot-plant system have been described in considerable detail elsewhere. For the present it is sufficient to say that the design of the full-scale plant was based on the data obtained.

Full-scale treatment plant

The plant has been designed to remove substantially all the monohydric phenol from the mixed coke oven effluent. Table 1 gives a typical analysis of the effluent into the plant. The plant consists basically of four aeration tanks each 26 ft. square and each provided with a *Simplex* surface aeration unit. The tanks are so arranged that the effluent may be treated in four tanks in series or in two streams of two. The tanks are of reinforced concrete construction and are provided with concrete walkways spanning the tanks. The *Simplex* surface aeration units are supported from the walkways and driven by two line shafts, each line shaft driving two aeration cones.

The *Simplex* cone consists of an inverted truncated sheet steel cone, provided with internal webs. As the cone rotates, the liquid within it is forced to rotate and is consequently flung out and across the surface of the tank, to be replaced by liquid drawn up the draught tube from the bottom of the tank.

The contents of the tank are thus aerated and mixed by the same mechanical device. Provision is made for altering the speed of the line shaft and hence the rate of rotation on the cones.

The spent liquor leaving the ammonia still is at boiling point, and too hot to treat directly on reaching the effluent plant. To cool the effluent and also maintain the temperature of the aeration tanks, the liquor is first passed through a pipe system in the base of the aeration tanks and then through a pair of rack coolers. The temperature of the first tank in each stream is controlled by an automatic controller which by-passes part of the hot effluent. The temperature of the second tank is controlled by the cooling

water supply to the rack coolers.

Since there is always the possibility of blockage or scaling of the heating tubes, these have been arranged as individual hairpins connected to a manifold outside the treatment tanks. The end of each hairpin is connected to a three-way cock in the manifold by means of a right-angle bend. By operating the three-way cocks and removing the bends, the hairpins may be isolated and cleaned without interrupting the operation of the plant.

The ammonia liquor contains a high proportion of the fixed ammonia, and lime is therefore added during distillation. It is essential that this lime should not be allowed to reach the aeration tanks and two settling tanks operating in parallel are therefore provided. Each settling tank has a mechanically driven scraper which leads the sludge into a central bottom off-take. The lime sludge is pumped

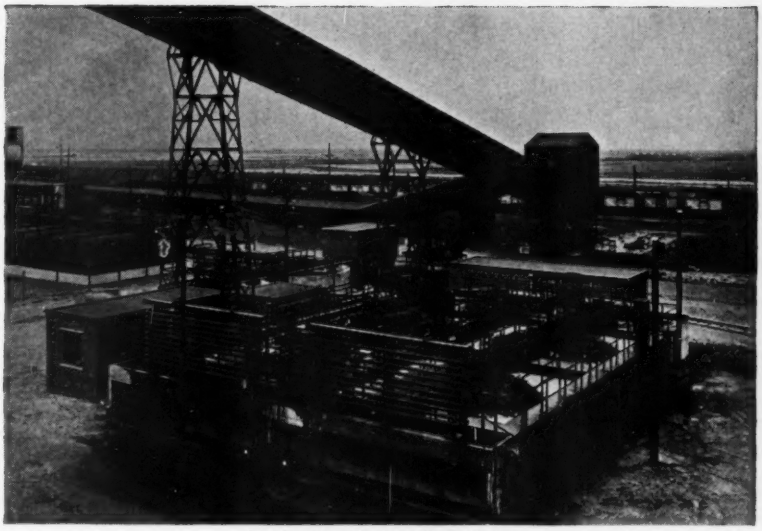

Fig. 2. Overall view of installation

Fig. 3. One of the aeration valves in operation

out as necessary into a road tank trailer. The sludge is then taken away for dumping.

From the settling tanks, the incoming effluent flows to a pumping sump where the *p*H is corrected, if required, by the addition of sulphuric acid, the amount being automatically controlled from the *p*H in the treatment tanks. Nutrient solution is also added at this point. The nutrient salts are dissolved in water and the addition carried out by means of a dosing pump.

The bacteria are dispersed throughout the effluent whilst it is being treated. By providing nuclei on which the bacteria grow, a settleable sludge is formed. The sludge is carried over the outlet weir from the aeration tanks and into two circular settling tanks. These tanks serve to remove the sludge from the effluent and recover it for re-use in the process. It is important that the sludge should not be starved of oxygen, hence particular attention is paid to the design and construction of a scraper gear. This is arranged to move all the sludge to the central well continuously. Similarly, return of sludge to the aeration tanks is carried out continuously by two sludge pumps. These are of a special type designed to avoid damaging the sludge during pumping. A third pump is installed as a common stand-by.

Control through the plant

Duplicate streams have been used to facilitate maintenance. The effluent is pumped from the collecting sump in the sulphate plant to the lime settling tanks, and the overflow from these leads into the effluent sump. The normal level of this is such that there is a reserve capacity of about 1 hr. normal flow. The effluent is then pumped from the sump through the heat exchanger system into a splitter box feeding the aeration tanks, the rate of pumping being controlled by a level controller. In each case the effluent flows out of the aeration tanks over adjustable weirs. The overflow from the peripheral weirs of the final settling tanks passes directly to the drain.

The plant has been designed to operate without continuous attention and a number of safety and alarm features are therefore incorporated. If one of the aerator drives stops, the feed to the affected aeration tanks is cut off and a warning is given to the operator in charge of the sulphate plant. The storage capacity in the effluent sump allows about 1 hr. at full flow during which time the trouble may be rectified. If and when the level in the sump reaches the maximum, another system diverts the flow of the incoming effluent to a lagoon.

Ancillary services

Sulphuric acid for *p*H control is received from rail tank wagons in a storage tank, and pumped from there into a small overhead tank from where it flows by gravity through an automatic control valve to the effluent pumping sump.

A small inoculum tank is provided for use when commissioning the plant.

This is simply a small tank provided with a means of aeration and a thermostatically controlled immersion heater.

Materials of construction

The materials of construction are for the most part traditional. The aeration and settling tanks are of reinforced concrete. The aeration cones are of mild steel and have been protected with a proprietary corrosion-resistant compound as have the scrapers installed in the lime settling tanks.

Pipework handling hot still effluent is mainly of cast iron and the penstocks, etc., controlling the flow of effluent from the tanks are also cast iron. Rigid PVC has been used for the nutrient feed pipework and the sludge return system.

Commissioning

Commissioning is normally carried out by using an inoculum prepared from freeze-dried cultures of bacteria. The cultures are supplied in glass tubes similar in size to a normal laboratory test tube. Before commissioning, all foreign matter is removed from the tank and the concrete work washed down to remove free alkali.

The inoculum preparation tank is then filled with effluent suitably diluted with water and one or more of the freeze-dried cultures suspended in water are emptied into it. The tank is aerated and the optimum temperature and *p*H conditions maintained. When the phenol concentration has been reduced to 10 p.p.m. the process is stopped, most of the liquid drained off and the process restarted with undiluted effluent. When the phenol concentration has again dropped to 10 p.p.m. the contents of the tank are transferred to the aeration tanks, using one of the sludge pumps.

Operating results

Fig. 4 shows a month's typical operation. During the early days of operation some difficulty was experienced due to abnormal conditions of operation in the process plant giving rise to the effluent. These difficulties have now been overcome and the plant is giving consistent results.

Operating costs

The plant represents a considerable advance in the design of plant for the biological oxidation of phenol. The ground space required and power costs are well below those of the type of plant previously used for the oxidation of spent ammonia liquor. It is too early to form an opinion on maintenance costs, but the present indications are that these will also be lower than those of the previous type of plant.

The cost of treating the effluent in the plant described, including an estimated amount for maintenance, but not including capital and depreciation charges, is about 1s. 8d./1,000 gal.

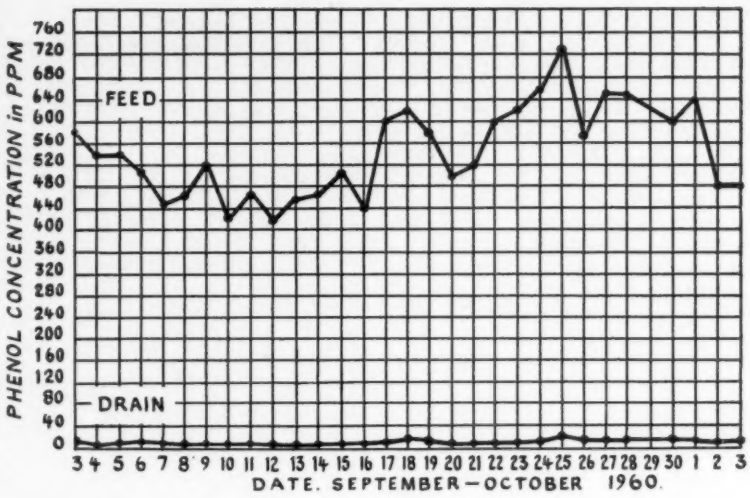

Fig. 4

General considerations

The plant described has been designed specifically for the oxidation of phenolic waste liquor from an ammonia still, but the methods used can and are being applied to other effluent problems. Plant for the oxidation of any effluent amenable to bacteriological treatment can be designed by using a similar approach, *i.e.* determining the optimum conditions in the laboratory and then designing the plant to provide these conditions.

Due consideration must be given to the economics of the problem, *e.g.* where no waste heat is available it may be preferable to increase the size of the plant and operate at a lower temperature, thereby saving on running costs. Once again, however, the laboratory investigation provides the information necessary to establish the most economical design.

Acknowledgments

The author is indebted to: Simon-Carves Ltd. for permission to publish this paper, the directors of John Summers & Sons for permission to include a description and photographs of their plant, and his colleagues in the research department of Simon-Carves for helpful criticism and advice.

Italian firm's patent rights

A lawsuit against Shin Nippon Chisso was filed recently with the district court of Osaka, Japan, by Montecatini Societa Generale per l'Industria Mineraria e Chimica Anonima of Italy. According to company spokesmen, Montecatini took this step after warnings to Shin Nippon Chisso; however this company showed that it intends to go ahead in its plans to manufacture polypropylene.

Polypropylene plastics were discovered in Italy about six years ago by Prof. G. Natta, in the course of research activities sponsored by Montecatini. Patents covering these discoveries have been obtained in most countries of the world and many of the more important chemical groups are now licensees under these patents.

In Japan, Montecatini and Prof. H. Ziegler have obtained basic patents and have also obtained, or are about to be granted, patents covering additional inventions. Mitsui Chemical and Mitsubishi Petrochemical have obtained Montecatini licences, and the relevant agreements, which have been approved by the Japanese Government, are expected to get final approval soon.

According to Montecatini spokesmen, Shin Nippon Chisso has not used Montecatini's licence, but has started on a course which Montecatini believes will lead to the infringement of their patents.

Treatment and Disposal of Radioactive Wastes

By R. H. Burns,* B.Sc., F.R.I.C.

The development of the atomic energy industry and the growing medical and industrial uses of radionuclides have presented many new problems in contamination control. The production of power from nuclear energy will tend to increase the difficulties experienced and it is essential that the position should be reviewed continuously in what are still the early days of the Atomic Energy Age.

IT is not possible for work with radioactive materials to be carried out without some release of ionising radiations to the environment. Nevertheless, it must be ensured that, regardless of cost, the amount discharged shall be controlled so that no danger arises to this or future generations. Acceptance of this maxim has meant that more money, thought and effort have been spent on this than on any similar problem. In the United States, for example, radiobiological research costs over $40 million p.a., and approximately $6 million are expended annually in the control of radioactive wastes. The figures for Great Britain and other Western European countries, though smaller, are very considerable.

A broad distinction can be made, both in quantity and quality, between the type of waste from the large users or producers of radioactive material and that from hospitals, university laboratories and industrial concerns using radionuclides.

In Great Britain by far the greatest amount arises from the work carried out by the Atomic Energy Authority; the waste from other sources is almost insignificant in comparison. Subdividing still further, the Authority's wastes vary considerably, ranging from the highly radioactive liquids, resulting from the processing of spent nuclear fuel, to the effluents from the research centres and isotope production units.

During the operation of a nuclear reactor a complex mixture of radioactive elements is formed in the fuel, collectively called fission products. The exact composition of the mixture depends on the type of fuel used and the rate of ' burn-up ' in the reactor. There are normally, however, over 30 elements so produced ranging from zinc-72 to dysprosium-161. These unwanted products serve as poisons in that many are strong neutron absorbers and as such tend to prevent the fission chain reaction continuing. This is one reason why the fuel has to be discharged from the reactor, the fission products removed, the residual uranium recovered for subsequent use, and the plutonium, which is also formed, separated.

Many of the fission products have short half-lives and decay very quickly. It is usual practice, therefore, to store the spent fuel under water for about three months to allow decay of the shorter-lived activities. Subsequently the outer can, which is frequently of aluminium, is removed by mechanical or chemical means. The irradiated uranium is then dissolved in nitric acid and treated by solvent extraction. Three streams result, one containing the plutonium, one the uranium and an aqueous solution in which is over 99% of the fission product nitrates.

Table I

Radionuclide	*Half-life*	*Maximum allowable concentration*	
		In body, μc.	*In water, μc./ml.*
Strontium-90	28 years	2.0	1×10^{-6}
Caesium-137	26.6 years	30.0	2×10^{-4}
Promethium-147	2.6 years	60.0	2×10^{-3}
Cerium-144	290 days	5.0	1×10^{-4}
Iodine-131	8.1 days	0.7 (thyroid)	2×10^{-5}
Zirconium-95	63 days	20.0	6×10^{-4}
Barium-140	12.8 days	4.0	2×10^{-4}
Ruthenium-103	41 days	20.0	8×10^{-4}
Ruthenium-106	1 year	3.0	1×10^{-4}
Strontium-89	54 days	4.0	1×10^{-4}

From the standpoint of waste disposal it is the fission products possessing the longest half-lives and/or those which have the lowest allowable concentration in the human body which are the most important. The principal nuclides in this connection are shown in Table 1, the figures quoted being those recommended for radiation workers.

Certain other wastes are produced at processing stations, but all are of very much lower activity level than the fission product solutions. For example, the water in which the fuel elements are stored becomes mildly radioactive due to slight faults in the cladding material or from contamination on the surface of the can. If mechanical decanning under water is practised, some release of activity from the irradiated fuel occurs. The acid dissolution of the fuel results in the

*Industrial Chemistry Group, A.E.R.E., Harwell.

release of volatile and gaseous fission products, and the final purification of the recovered uranium and plutonium produces dilute wastes.

Solid waste also arises; many materials when used in contact with radioactive material adsorb or absorb radioactive ions and it is sometimes difficult, if not impossible, to decontaminate them to permit re-use. Filters, fuel element cladding material, graphite supports and spacing rods from the reactors are other sources of waste.

Next in importance are the effluents from the Authority's other establishments dealing with the production of uranium from ore or concentrates, the preparation of specific radioisotopes, and research on all aspects of atomic energy. Although the activity level of these is small in comparison with that of the processing wastes, it is frequently higher, by several orders of magnitude, than that of wastes produced by other users. The wastes can be in the solid, liquid or gaseous form and, in general, do not differ greatly from those produced in other industries or laboratories except that they are contaminated with radioactive material and are, normally, greater in quantity.

Wastes from power reactors

One important aspect in the near future will be the planned development of the power programme. The nature of the wastes produced will depend on the type of power reactor favoured. In Great Britain, for the first phase at least, gas-cooled reactors fuelled with natural uranium have been chosen. The coolant is carbon dioxide, which is circulated through the reactor and the heat exchangers, the heat extracted being used to produce steam which is then employed to generate electrical power by conventional means. There will obviously be a considerable increase in the amount of irradiated fuel to be processed and a consequent increase in the fission product wastes. However, these will not arise at the power stations, as it is the intention in Great Britain to process all spent fuel at one or two existing chemical plants.

The following estimate has been made of the arisings at a 200-MW station of the gas-cooled type:

(*a*) About 10 millicuries/sec. of argon-41 in the shield cooling air which is drawn between the pressure vessel containing the reactor and the biological shield. This is due to the irradiation of the argon present in the cooling air. Irradiated dust particles and corrosion products may also be present.

(*b*) Up to 200 curies, mainly of argon-41, discharged periodically with the carbon dioxide coolant. This will contain also small quantities of uranium oxide and fission products arising from surface contamination or slight rupture of the fuel element cans. There will also be a general loss of carbon dioxide from the primary coolant circuit which will result in the release of some activity (estimated at approximately 10 curies/day), mainly argon-41 and nitrogen-16.

The chief liquid waste will be from the storage pond water, estimated at 250 millicuries/day, with much smaller contributions from laboratories and decontamination procedures. The usual miscellaneous collection of materials will constitute the solid radioactive waste. Of these only the filters used in the gas cooling circuit and any sludge formed in the storage ponds will require special methods of disposal.

The use of radionuclides in hospitals is increasing slowly, but the majority of the radioisotopes used have short half-lives. Over half the activity supplied consists of gold-198 and there are major contributions from iodine-131, sodium-24, phosphorus-32 and bromine-82. At the present time, in Great Britain, slightly less than 30 curies are supplied to hospitals each month, and it is estimated that not more than a quarter of this amount will appear in the waste. Further decay will take place before this is discharged from the premises.

Radium sources used are on loan from the Radiochemical Centre, and are subjected to a strict accounting system. Other teletherapy sources, containing several hundred curies of cobalt-60 and caesium-137 are gaining favour as alternatives to X-ray units. These are too valuable to be discarded lightly and in the case of cobalt-60 can be, and are, returned for re-irradiation. Caesium-137 cannot be so treated, and disposal of such sources, when they have decayed to a useless level, will require special attention.

Over 90% of the radioactive material used by industry is in the form of solid sources. The most extensively used is iridium-192 for radiography, and this can be re-irradiated. Smaller amounts of radioactive material are either produced in or used by the thorium and phosphorus industries, in luminising and in the manufacture of valves and certain starting switches.

Treatment and disposal

A characteristic distinguishing radioactive wastes from the more common industrial unwanted products is that their active components are not detected by human senses. Further, there is no known chemical or physical means of destroying the potentially hazardous nature of the material; it becomes inactive only by natural decay. A further difficulty is in defining what is a radioactive waste. All material is radioactive to some extent and so the division must be an arbitrary one. It is convenient, and usual, to define such material as one produced in the extraction or subsequent use of natural radionuclides or in the production, extraction or use of artificial radionuclides.

There are at least a hundred radionuclides which are extracted, prepared and used and which, in consequence, may be discharged to the environments. The chemical properties and physical form of the material in question vary enormously and, in consequence, it is not possible to lay down standard methods of treatment; each case must be considered as a separate problem. Certain general principles can, however, be stated.

Broadly speaking, there are only two methods which can be adopted, *viz.* concentration and containment or dispersal. The first would appear to be the simplest solution; it is also highly reassuring and it eliminates the need for investigations into the behaviour of radioactivity in the environment. It is, however, neither necessary nor desirable and the cost of containing all the large volumes of waste produced would be prohibitive. The problem thus resolves itself into deciding what must be stored and what can safely be dispersed.

There has never been any serious suggestion made in any country that the processing wastes, as described previously, can be discharged. The long half-lives of many of the isotopes present, and the high specific activity, necessitates guaranteed supervision and control for hundreds of years. The accepted practice is to store these liquors in high-integrity tanks in selected areas. It is usual to evaporate the solutions as far as practicable in order to minimise the volume to be stored. A unique property of such waste solutions, which is associated with their intense radioactivity, is that they are capable of spontaneous and prolonged boiling because of the absorption of their own radiant energy. The heat emission rate may be as high as 20 B.T.U./hr./gal. Attempts

have been made to utilise this heat to provide self-evaporation, but unfortunately the rate of heat release is not regular and violent surging can occur, leading to rapid fluctuation in pressure build-up. In designing such tanks it is necessary to cater for changes in both internal and external pressure and to provide means to minimise the effects of the uncontrolled boiling. An air lift agitator or circulator for the liquid has been used with success.

In the United States the wastes are generally neutralised and then stored in mild-steel-lined, reinforced-concrete tanks. In Great Britain these liquid wastes are always stored in the acid state in stainless-steel vessels. It is considered that the superior corrosion resistance of alloy steel is an added safety factor and, further, that neutralisation favours the formation of precipitates which encourage undesirable surging during storage.

The tanks are heavily shielded or situated below ground. Elaborate precautions are taken to ensure early warning of any leakage. Frequently the tanks are contained within another tank with monitoring facilities in the outer container. In addition, wells are drilled in the storage area which permit monitoring of the environment. In the United States alone over 65 million gal. of high-level wastes have accumulated and are stored as described. The general consensus of opinion is that tank storage is not the ultimate answer, but that present methods are safe and that temporary (two to ten years) storage will always be an integral part of any ultimate system.

Decontamination factor

Certain other liquid wastes are also of too high an activity level to permit direct dispersal to the environments, but for these some form of treatment is possible. It must be emphasised that treatment does not destroy the radioactivity, it merely transfers it to some other form of waste which can be handled more satisfactorily. One of the most efficient, but expensive, methods of achieving this is by evaporation. Many different types of plant are operating satisfactorily, ranging from forced-circulation flash evaporators operating at reduced pressure, to simple single-effect types consisting of a kettle in which steam coils are mounted and operating at atmospheric pressure. The decontamination factor obtained (*i.e.* the ratio of the activity level of the original liquid to that of the treated effluent) depends very largely on the de-entrainment columns used. Raschig rings, bubble plates and glass wool or woven metallic filters have been used with success. Difficulties can arise from foaming and scale-forming solids which may necessitate prior chemical treatment. In spite of the difficulties, evaporation is a process which will give the highest decontamination factors (10^6 to 10^7) and is attractive when waste steam is plentiful, as may well be the case at nuclear power plants.

There are differences of opinion as to the stage at which evaporation should stop. At the Risø research establishment in Denmark it is planned to evaporate to dryness, whilst at other stations it is considered that this could give rise to an airborne dust hazard. The usual practice is to stop at the commencement of crystallisation and to absorb the residue in exfoliated vermiculite or fix in concrete, after which it is handled as solid waste.

Ion exchange

Another method frequently employed is conventional ion-exchange techniques. Normally, passage through a cation exchanger will suffice, as only a few radionuclides are in the anionic form and these are mostly short-lived isotopes. Better results can sometimes be obtained by using a mixed bed consisting of an intimate mixture of cation and anion exchange materials.

Decontamination factors as high as 10^6 have been claimed, but these have been on special solutions; a more realistic figure is 10^3. The best results are obtained using the high-capacity synthetic resins, but these cannot be used for highly active liquids as, in common with all organic matter, they tend to degrade under irradiation. One disadvantage is that ion exchangers will remove inactive ions with equal efficiency which, in this connection, means using up the ion-exchange capacity to no advantage. Regeneration of an exhausted resin column gives rise to a concentrated solution which requires further treatment to make it safe for storage or disposal. It is for this reason that it is not uncommon to eliminate regeneration and treat the exhausted columns as expendable. Owing to the high cost of the synthetic resins, attention has been paid to the use of cheap naturally occurring ion-exchange material. Vermiculite has been used with success and lignite, clinotopholite and montmorillonite have been suggested. If these natural products are used, regeneration is not attempted and the overall cost is reduced significantly.

Chemical precipitation

Of all the methods employed for the treatment of low- to medium-level radioactive liquid effluents, chemical precipitation is the most widely practised. Although the decontamination factors obtained are not high, the method is economical and adequate for the large - volume low - activity wastes which arise daily at many atomic energy establishments. The object of the chemical treatment is to concentrate the radionuclides into a small bulk of insoluble sludge which can be separated. This reduces the activity level of the main volume of effluent sufficiently to permit dispersal to the environments.

The chemicals used vary to some extent depending on the radionuclides present and the decontamination required. In general, a high *p*H value is advantageous and it is usually necessary to add a ' weighting ' agent owing to the small mass of contaminant present. The normal practice at the Atomic Energy Research Establishment at Harwell is to raise the *p*H value to approximately 11.0 with sodium hydroxide and to form, *in situ*, a precipitate of hydroxy apatite by the addition of calcium salts and trisodium phosphate. Frequently a denser precipitate is obtained if an iron salt is also added as a conditioning agent. The precipitate is then removed in conventional apparatus such as sludge blanket precipitators or clarifiers. Certain radionuclides are not removed efficiently by this method, notably radio-caesium. When this is present, co-precipitation with copper ferrocyanide is advantageous or the effluent after the phosphate treatment can be passed through a column of synthetic or naturally occurring ion-exchange material. Fig. 1 shows a typical flow diagram which incorporates all the commonly employed processes for the treatment of radioactive liquids.

Direct dispersal

Certain liquid effluents are sufficiently dilute to permit direct dispersal and this is carried out to sewers, to rivers or to the sea, depending on the geographical location of the particular establishment. No dispersal of treated or untreated waste is authorised without the most careful examination of all relevant factors. It is not sufficient to prove that the waste in itself is innocuous, it is necessary to show that any concentration processes which might occur will not create a hazard. One example will illustrate the philosophy which must be adopted. The U.K.A.E.A.

has recently established a reactor testing station at Winfrith in Dorset. One of the reasons for selecting this site was the proximity of the sea. It was considered that certain of the low-level liquid wastes could be discharged with safety off the Dorset coast. In order to substantiate that this was in fact the case, a full-scale investigation was undertaken. During the exercise over 32 tons of a fluorescent dye were discharged over three months at various states of the tide and in varying weather conditions. A comprehensive sampling programme was carried out during and after the discharges, and the results obtained enabled a clear picture to be obtained of the dispersion and dilution in this sea area.

Next, the ways in which the public might be irradiated as a result of the discharges were examined. These included the consumption of fish, through any possible use of the seaweed, the handling of fishing equipment and recreation on the sea shore. The final authorisation granted was such that no hazard could arise either to person or property. Once radioactive discharges have commenced, thorough environmental surveys will be carried out and the results obtained will decide if any alteration is required in the authorised amount.

Small users of radioactive material would wish to discharge their liquid wastes to the local sewers and for low-level effluents this is a satisfactory disposal method. Recommendations have been made that the activity level in the sewage from the establishment should not exceed 10^{-4} μc./ml. Assuming a normal water usage this would allow the discharge of approximately 2 mc./day for every 100 people employed in the establishment. The chief potential hazard seems to be possible danger to men working in the sewers or handling the sewage. It is reasonable to assume a dilution of at least 100 in the effluent on reaching the main sewer or the sewage works. The final average concentration would then be 10^{-6} μc./ml. The formula used for obtaining the radiation dose inside on infinite media is:

$$S.\ E. \times 2.15\ \text{r./hr.}$$

where S = μc./g. (or per ml.) and E = energy emitted in MeV. An average figure for E is 0.8, which means that in the case under consideration, if any one person was totally immersed in the contaminated sewage for 40 hr. in any one week, he would receive a radiation dose of 0.07 millirad compared with 10 millirads, which is the maximum weekly dose considered safe by the International Commission on Radiological Protection.

Solid wastes

The disposal of solid radioactive wastes requires special attention, as dilution is difficult if not impossible. The commonly accepted methods are storage, burial or sea dumping. Burial should only be practised in geologically satisfactory areas, the future use of which can be guaranteed. Municipal tips could be used, provided the radioactive material is contained, buried beneath several feet of other rubbish and the amount per container restricted to microcurie amounts of long-lived nuclides or millicuries if the half-life is less than one year.

Some criticism has been levelled at sea dumping but, provided the amount disposed of is restricted, the depth of water considerable and special attention paid to the design of containers, then the potential hazard can be

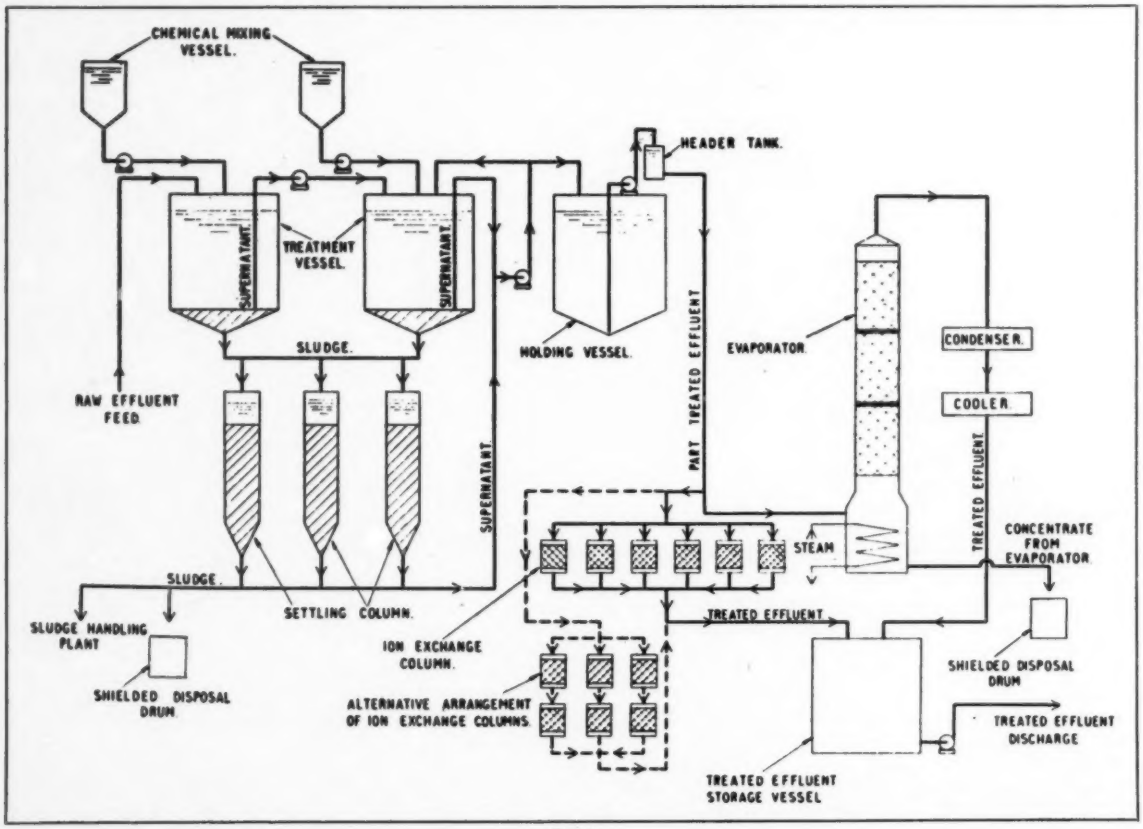

Fig. 1

eliminated. The U.K.A.E.A. is permitted to discharge into a specified sea area up to 200 c. of α radioactivity and up to 4,000 c. of β-γ radioactivity p.a. The limits set can be shown to be extremely safe and the radioactivity discharged in this way is insignificant when compared with the natural activity of the sea-water.

Gaseous effluents are invariably discharged to the atmosphere at such a height as to ensure that the concentration in air at ground level does not exceed one-tenth of the level considered acceptable by the International Commission on Radiological Protection. In the case of all important discharges, filtration or scrubbing systems are used to remove particulate matter and volatile radionuclides.

The future

Although present methods of treatment and disposal are safe and adequate, it is the duty of all concerned to ensure that doses to the population are kept as low as practicable and that any unnecessary exposure is avoided. With this aim in mind, continuous work and thought are being directed to exploring even safer methods and ones that will cope with the increased arisings foreseen in the future. Much effort is being directed towards the conversion into solid form of the highly active processing wastes. As such wastes may require permanent storage, it would be of advantage if they were in the solid state, particularly if the mass can be made resistant to leaching by water. In Canada the use of nepheline syenite, a material employed in the glass and pottery industry, is favoured. It has been shown that a mixture of this mineral with lime will readily incorporate 5% fission product oxides. The final mix is fired to temperatures of over 1,000°C. and the resultant ceramic shows promising non-leaching properties. British and some American experiments have been directed towards flash evaporation of the radioactive solutions in the presence of suitable fluxes such as silica and borax. Subsequently, the temperature is raised to approximately 1,100°C. when a glass is formed.

Although many of the glasses produced have exhibited good non-leaching properties, there is as yet no knowledge of the stability of the material under long-term irradiation. Current opinion is that the glass should be contained in a high-integrity container and stored under controlled conditions at least until further experience is gained.

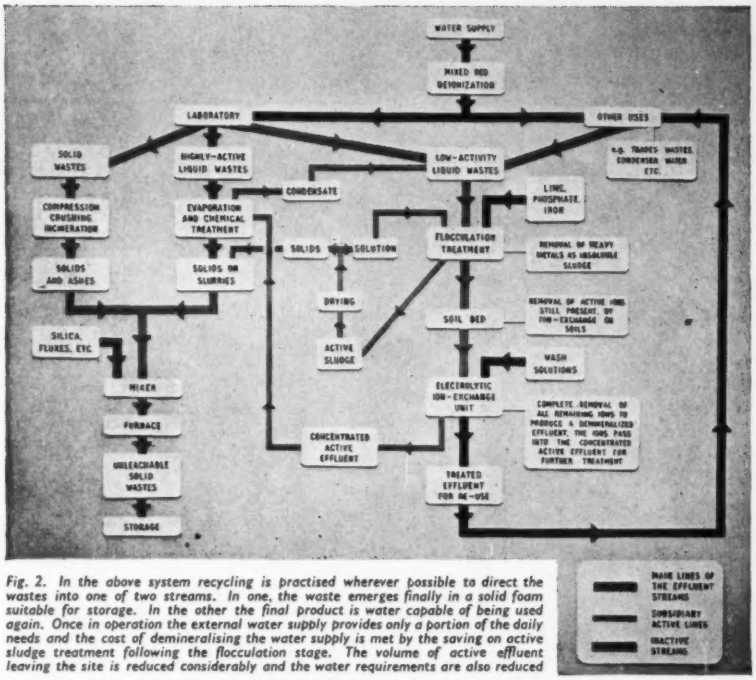

Fig. 2. In the above system recycling is practised wherever possible to direct the wastes into one of two streams. In one, the waste emerges finally in a solid foam suitable for storage. In the other the final product is water capable of being used again. Once in operation the external water supply provides only a portion of the daily needs and the cost of demineralising the water supply is met by the saving on active sludge treatment following the flocculation stage. The volume of active effluent leaving the site is reduced considerably and the water requirements are also reduced

In the United States consideration is being given to the use of exhausted salt mines for the storage of radioactive wastes. Salt has considerable compressive strength and is plastic under load. In consequence, excavations in salt beds are normally dry and therefore attractive as storage space. Another approach has been to explore the possibility of disposal into deep wells, as is the practice in the petroleum industry for waste brines. Many deep, porous beds and sedimentary rocks contain water trapped in them when they were deposited millions of years ago. If injection into these could be made it is reasonable to suppose that retention could be expected.

Meanwhile, work is continuing to improve existing methods of treatment and disposal. One approach is to aim for self-containment and retain on the site and/or to re-use the wastes produced. One possible scheme is shown in Fig. 2. Such an approach is feasible, but would be expensive and may not be desirable. It must be realised that complete containment is not possible and that the maximum concentration practicable may present a greater hazard than controlled dispersal of certain waste material.

One major step toward greater control of radioactive waste in Great Britain will be taken when the Radioactive Substances Act, 1960, is implemented.

The controlling Minister is given powers under the Act to set up a national disposal service and, if necessary, a national disposal site.

The problem of the disposal of radioactive wastes is indeed difficult. Only by neither ignoring nor exaggerating the difficulties will a rational solution be reached and thus allow the use of radioisotopes and the development of power from atomic energy to proceed as planned.

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Simultaneous Heat and Mass Transfer

By F. Molyneux,* Ph.D., B.Sc.(Lond.), B.Sc.(Eng.), A.M.I.Mech.E., A.M.I.Chem.E.

An important process on many chemical plants is the direct contacting of a fluid with a gas to effect an exchange of heat, such as saturating of gases with water vapour by contact with water and the cooling of hot gases with cold water. All these involve gas/water vapour as the two components, but a similar process involving direct contact of a saturated hot gas stream with a cooler liquid stream of the same composition as the condensate has been utilised for many years in the chemical industry, notably in washing out tar from hot coal gasification retort gases. These operations are usually carried out in towers filled with packing, the process in each case being one of simultaneous heat plus matter transfer, in which the heat is transferred as sensible plus latent heat. This article describes the design of several processes based on this type of transfer mechanism.

THE dual nature of simultaneous heat and mass transfer between the phases does not lend itself to a fundamental and accurate treatment sufficiently simple for general use, and in practically all cases other than air/water vapour over a limited temperature range a trial and error solution is required utilising the well-known analogy between the transfer of heat and matter along the same path.

In the case of water cooling, however, the so-called total heat method has been used for a number of years. It expresses both heat and matter transfer in terms of a single equation of the form:

$$\begin{pmatrix}\text{Total heat transferred}\\ \text{to or from water}\end{pmatrix} = \begin{matrix}(\text{Transfer coefft.}) \times (\text{transfer area})\\ \times (\text{mean driving force})\end{matrix}$$

Unfortunately, the approximations inherent in this approach are inaccurate with increasing temperature and vapour pressure and, in practice, restricts the use of the water cooling tower treatment to temperatures less than 104°F.

For consideration of any system other than air/water vapour, recourse must be made to the fundamental equations governing the transfer of heat and matter and the consequent balancing overall transfer of heat as sensible plus latent heat transfer between the phases.

Consideration will first be given to the partial condensation of a vapour from an inert gas.

Partial condensation of vapour from inert gas

If a mixture of a vapour and a gas is cooled in a constant-pressure operation, the temperature at which the first drop of condensate appears is the dewpoint, being the saturation temperature of the vapour corresponding to its partial pressure in the mixture.

When a mixture of a vapour and a non-condensable gas is fed to a cooler, the temperature of which is below the dewpoint for the vapour, a film of condensate will form at the point of contact. The partial pressure of the vapour at this point of contact, or at the temperature of the condensate film, must be lower than that in the bulk of the gas in order to provide a driving force for further mass transfer of the vapour by diffusion to produce more condensate.

The mechanism can therefore be seen to be a combination of sensible heat transfer from the vapour and gas and a latent heat mass transfer by the vapour.

Colburn[1] has demonstrated the analogy between the mechanisms of heat and mass transfer, and their relationships are essential in providing a basis for the design of coolers where a combination of heat and mass transfer is taking place.

In the condensation of a vapour from a non-condensable gas, the quantity of heat which leaves the gas film must equal the quantity taken up by the coolant.

The total heat flow across the gas film is the sum of the latent heat carried by vapour diffusion into the condensate

Symbols used in this article

A	=	Transfer area, sq.ft.
a	=	Specific surface of packing, sq.ft./cu.ft.
C_p	=	Specific heat of dry gas, B.T.U./lb.°F.
C_s	=	Humid heat, B.T.U./lb.°F.
G	=	Gas rate on dry basis, lb./hr.
h	=	Convectional heat transfer, B.T.U./hr.sq.ft.°F.
i	=	Enthalpy, B.T.U./lb.
K_g	=	Overall mass transfer coefficient, mols./hr.sq.ft.atm.
L	=	Liquid rate, lb./hr.
M	=	Molecular weight
ρ	=	Dry gas density, lb./cu.ft.
ρ_l	=	Liquid density, lb./cu.ft.
V	=	Volume of packed section, cu.ft.
λ	=	Latent heat of vaporisation of liquid, B.T.U./lb.
D	=	Diffusivity of vapour in inert gas, sq.ft./hr.
K	=	Gas conductivity, B.T.U./ft.hr.°F.
dN	=	Differential mass transfer rate, lb./mol./hr.
P	=	Total pressure (atm.)
R	=	Gas constant
T	=	Absolute temperature
μ	=	Gas viscosity, lb./ft./hr.

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film, plus the sensible heat removed from the gas because of the temperature difference between gas and condensate $(T_g - T_c)$.

For a tubular condenser the heat load expressed in terms of the shell side, tube side and overall potentials per square foot of surface when the mixture of gas and vapour flows in the shell is:

$$h_o(T_g - T_c) + K_g M_v \lambda (p_v - p_c) = h_{io}(T_c - t_w) = U(T_g - t_w)$$

where h_o = shell side dry gas coefficient, B.T.U./hr. sq.ft.°F.
h_{io} = tube side water coefficient, B.T.U./hr.sq.ft. °F.
T_g = temperature of the gas, °F.
T_c = temperature of the condensate, °F.
t_w = water temperature, °F.
p_v = partial pressure of vapour in the gas body, atm.
p_c = partial pressure of the vapour at the condensate film atmosphere
M_v = molecular weight of vapour, dimensionless
λ = latent heat, B.T.U./lb.
k = thermal conductivity, B.T.U./sq.ft.hr.°F./ft.
c = specific heat, B.T.U./lb.°F.

The Colburn j_H factor of heat transfer can be defined as:

$$j_H = \frac{h}{cG}\left(\frac{c\mu}{k}\right)^{\frac{2}{3}} = \frac{t_2 - t_1}{\Delta t}\left(\frac{a}{A}\right)\left(\frac{c\mu}{K}\right)^{\frac{2}{3}}$$

and similarly, j_D, the mass transfer factor, as:

$$j_D = \frac{K_g p_{gF}}{G/M_m}\left(\frac{\mu}{\rho D}\right)^{\frac{2}{3}} = \left(\frac{p_1 - p_2}{\Delta p}\right)\frac{a}{A}\left(\frac{\mu}{\rho D}\right)^{\frac{2}{3}}$$

Equating j_H to j_D and solving

$$K_g = \frac{h(c\mu/k)^{\frac{2}{3}}}{c\, p_{gF}\, M_m(\mu/\rho D)^{\frac{2}{3}}}$$

where A = diffusion surface, sq. ft.
a = flow area of gas and vapour, sq. ft.
G = mass velocity, lb./hr.sq.ft.
K_g = mass diffusion coefficient, mols./hr.sq.ft., atm.
M_m = mean molecular weight of the vapour and non-condensable lb.mols.
p_c = partial pressure in atm. of the vapour at condensate film atmosphere.
t_c = p_t value of t_w

The method of application suggested by Chilton and Hougen is as follows:

(1) From the process conditions compute h_o and h_{io} for the gas and cooling medium respectively. The use of an average value of h_{io} is acceptable.
(2) From the value of h_o and the Chilton Colburn analogy estimate K_g/p_{gF}.
(3) Fix the temperature of gas T_g for the first interval, simultaneously fixing the heat load q.
(4) Assume values of T_c the condensate temperature, so that $h_o(T_g - T_c) + K_g M_v \lambda (p_v - p_c) = h_{io}(T_c - t_w)$. For each assumed value of T_c calculated a new value of p_{gF} for the vapour pressure at the condensate film corresponding to T_c.
(5) Calculate dA for this interval from $\dfrac{dV}{U(T_g - t_c)}$
(6) Repeat for the next interval, assuming a lower value of T_g.

Design of cooler condensers

Bras[5, 6] and Cairns[7] have discussed the design of cooler condensers in detail and the approach of Bras derived from above using the trial and error procedure of Chilton and Hougen, but employing a graphical technique to ease the labour, has found extensive use.

This utilises a vapour-pressure temperature plot of the pure condensing component on which is plotted an operating line for an incremental change of temperature and partial pressure in a similar manner to that used for cooling tower design.

The slope of this operating line is derived in the following manner:

$$dq_c = h(T_g - T_c)dA = Gc_p dT_g \quad \ldots\ldots\ldots\ldots (1)$$

$$dN = K_g(p_g - p_c)dA = \frac{G}{M}\left(\frac{p_g}{p - p_g}\right) \quad \ldots\ldots (2)$$

Dividing (1) by (2):

$$\frac{h}{K_g}\left(\frac{T_g - T_c}{p_g - p_c}\right) = C_p M (P - p_g)\frac{dT_g}{dp_g} \quad \ldots\ldots\ldots (3)$$

Using the equality of Colburn j factors, previously enumerated, and substituting in (3):

$$\frac{dT_g}{dp_g} = \left(\frac{p_{BM}}{p - p_g}\right)\left(\frac{Sc}{Pr}\right)^{\frac{2}{3}}\left(\frac{T_g - T_c}{p_g - p_c}\right) \ldots\ldots (4)$$

dT_g/dp_g gives the slope of the operating line, providing an assumed value for T_c p_c has been taken.

This equilibrium point $(T_c\ p_c)$ for a given incremental step must be found by trial and error, a value being chosen from the vapour pressure curve for the pure volatile liquid, and the corresponding incremental step for the gas stream is drawn in using the slope of the operating line calculated from equation (4).

Summation of the sensible heat transfer represented by dT_g and the latent heat transfer represented by dp_g must be equal to that taken up by the cooling fluid with a temperature difference $(T_c - t_w)$ where t_w is the cooling fluid temperature.

If this temperature difference $(T_c - t_w)$ is too large or too small, an incorrect value of T_c has been assumed and a fresh assumption has to be made until a balance is achieved.

Summation of the differential areas of transfer obtained in this manner provides the full surface area for heat exchange of the condenser for the design conditions.

Approximation of transfer coefficients

Silver[3] gives approximate methods for different types of cooler condensers for estimating the gas film sensible heat-transfer coefficient and the mean overall heat-transfer coefficient. The calculations necessitate knowing the area of an existing condenser and its operating terminal conditions. Conversely, the methods are applicable to the estimation of the surface area if the gas film sensible heat-transfer coefficients are known.

The methods are based on the assumption that h_s is constant throughout the cooling process and that the ratio of the sensible heat-transfer coefficient to the total gas film heat-transfer coefficient is equal to the ratio of the sensible heat capacity change to the total heat capacity change. However, the calculation of the area required for a given set of conditions does not appear possible where the values of h_s are not known for various equipment

under different operating conditions, or where it is not possible to assume h_s is constant.

Colburn has presented an approximate design method which involves only the terminal conditions of the condenser and eliminates the need for point-to-point heat balances and the trial and error calculation in order to obtain $U\Delta t$. In this method the overall driving force from mixture to cooling water is expressed as an enthalpy difference $(i_g - i_w^*)$ and the conductance of heat is expressed as an overall coefficient per unit enthalpy difference U_s/c_s such that:

$$\frac{dq}{dA} = \left(\frac{U_s}{c_s}\right)(i_g - i_w^*)$$

U_s/c_s is obtained from the following equation:

$$\frac{1}{U_s/c_s} = \frac{1}{h_s/c_s} + \frac{1}{h_o/m}$$

and m (slope of enthalpy/temperature curve) is evaluated at T_g.

Assuming U_s/c_s constant, then integration gives:

$$A = \frac{q}{(U_s/c_s)(\Delta i)_m}$$

Since U_s/c_s varies from inlet to outlet of the condenser, the arithmetic mean of the values at inlet and outlet is taken and used in the above equation.

c_s = humid heat B.T.U./lb.

R. C. Cairns[7] applied the above procedures for design calculations to known experimental conditions and found the Colburn and Hougen method gave an area in good agreement with the area verified for the experimental conditions.

The approximate method of Colburn applied to the same conditions was shown to give an area which was found to be approximately 40% greater than that needed for the systems investigated.[2]

The problem of the recovery of volatile material from an inert hot gas stream can be met by the provision of either a cooler condenser or a cooler scrubber, the decision being complicated less by the factor of minimum capital expenditure than by the process problems connected with the fouling of surfaces and consequent maintenance.

Cooler absorber

In a similar field of usage to both of these is the cooler absorber, the advantages of which have been enumerated in an article by C. G. Gardner.[4] According to this article the design basis is the same for either the cooler absorber or the cooler condenser, and can be stated to be derived from the approach of Colburn and Hougen,[1] modified in later papers by Bras[5] and by Cairns,[7] originating fundamentally from the Colburn equivalence between the j_H and j_D factors previously enumerated.

The scrubber cooler and the condenser cooler are used industrially for the performance of the same operation of simultaneous heat and mass transfer and a description of industrial methods of design is discussed by Silver,[3] although there is some prejudice against the direct contact of water with high-temperature gas, since it is felt that some frothing or boiling might take place.

Kern[6] has shown in three typical cases that, dependent on the inlet water temperature and its consequent vapour pressure, the normal mass transfer will be from the gas to the liquid and not *vice versa*.

The transfer mechanism is a combination of heat and mass but, dependent on the gas cooling range, the extent of the mass transfer is relatively small compared with that of sensible heat transfer in contradiction to the position in the corresponding tubular condenser, where the major portion of the heat load is caused by the mass transfer.

Calculations for washer cooler

The total cooling effect in a tower is due to the heat transferred by convection (q_c) and that due to diffusion (q_d). The three basic equations are:

$$dq_c = ha\,dV\,(T - t) \quad = G\,c\,dT \quad \ldots\ldots\ldots (1)$$

$$dq_d = K_g \lambda a\,dV\,(H - H^1) = \lambda dL \quad \ldots\ldots\ldots\ldots (2)$$

$$Lcdt = G(di) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Combining these three equations, the combined heat transfer q is given by the sum of the two modes of transfer and $dq = dq_c + dq_d = h\,adV(T - t) + K_g\,adV\lambda(H - H^1)$

$$= G\,(di) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The mass- and heat-transfer coefficients are related to each other by the Lewis equation:

$$\frac{h}{K_g c} = Le$$

For air/water diffusion the Lewis number is $\simeq 1$.

Regrouping equation (4):

$$dq = K_g\,adV\left[\left(\frac{hT}{K_g} + \lambda H\right) - \left(\frac{h_t}{K_g} + \lambda H^1\right)\right]$$

which can be reduced to:

$$dq = K_g\,adV\left[(i^1 - i) + c(T - t)\left(\frac{h}{K_g} - 1\right)\right] = G\,di$$

Using a Lewis number of 1, this reduces to the normal equation for cooling of towers:

$$K_g\,adV\,(i^1 - i) = G\,di$$

or:

$$\int \frac{di}{i^1 - i} = \frac{K_g a}{G}\int dV$$

The number of transfer units N.T.U. is given by:

$$\text{N.T.U.} = \int \frac{di}{i^1 - i}$$

and, by using equation (3) with $c = 1$ for water, the number of diffusion units can be obtained, denoted by:

$$\text{N.D.U.} = \int \frac{dt}{i^1 - i} = \frac{K_g a}{L}\int dV$$

This simple relationship only applies to simple cooling of air by water and, for the usual vapour liquid cooling, the number of diffusion units must be obtained by simultaneous integration of the equations (1), (2) and (3), normally calling for a trial and error solution.

Calculations for a cooler condenser

In the condensation of a vapour from a non-condensable gas the quantity of heat which leaves the gas film must equal the quantity of heat picked up by the cooling water.

The total heat flow across the gas film is the sum of the latent heat carried by vapour diffusion into the condensate

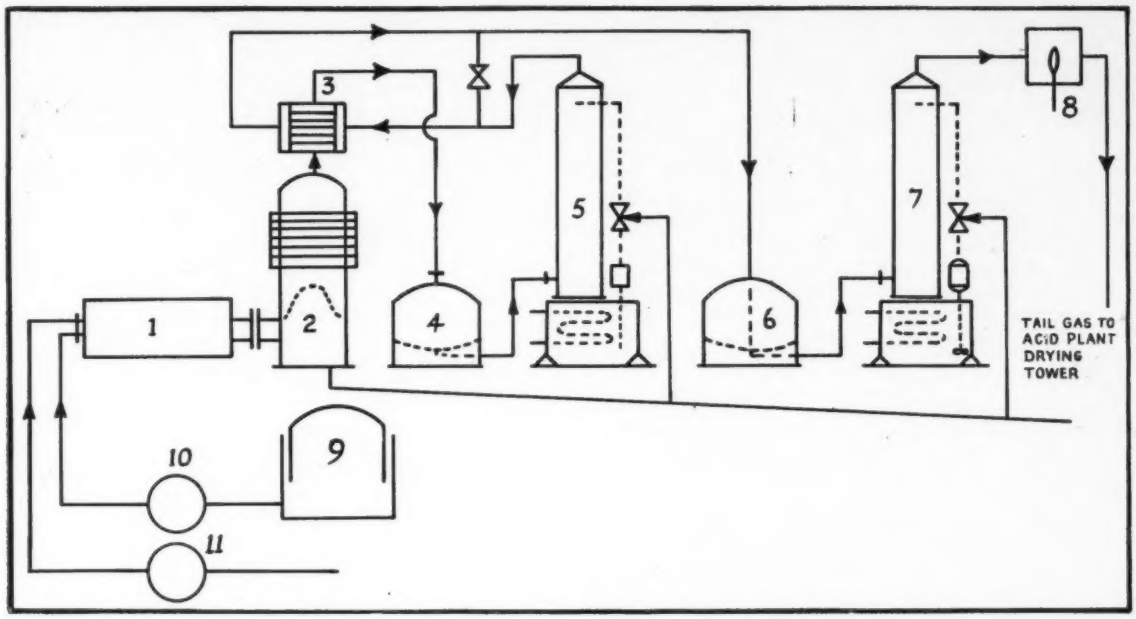

Fig. 1. Schematic plant diagram sulphur recovery from by-product hydrogen sulphide gas

1. Firebrick-lined furnace. 2. Fire tube vertical boiler. 3. Gas-to-gas heat exchanger. 4. No. 1 converter. 5. No. 1 sulphur scrubber cooler. 6. No. 2 converter. 7. No. 2 sulphur scrubber cooler. 8. Line burner for exhaust gas. 9. Hydrogen sulphide gasholder. 10. Hydrogen sulphide blower. 11. Air blower

film, plus the sensible heat removed from the gas because of the temperature difference $(T_g - T_c)$:

$$dq_c = h_o (T_g - T_c)\, dA \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$dq_d = K_g M_v \lambda (p_v - p_c)\, dA \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$dq = dq_c + dq_d = h_{to} (T_c - t_w)\, dA$$
$$= U (T_g - t_w)\, dA \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The film coefficient varies from inlet to outlet, but, in addition, the heat distribution varies also in a manner which is generally non-linear with temperature from inlet to outlet owing to a differential rate of change in the enthalpy of the vapour mixture as the temperature falls.

The surface is then defined by the equation:

$$A = \int \frac{dq}{(U\, dt)}$$

The integration is performed graphically ($dq = q$) for small intervals down the condenser. Again this calls for simultaneous integration of equations (1), (2) and (3), normally calling for a trial and error solution.

Sulphur scrubbing in sulphur recovery

The sulphur shortage of 1952 focused world attention on the maximum recovery of sulphur arising as a by-product in various industrial processes. Probably the most important of these sources of by-product sulphur is that occurring in sour petroleum crude and sour petroleum gas.

The presence of hydrogen sulphide and mercaptans in sour crudes renders these products unfit for most uses because of the toxic nature of the contaminants and the corrosive conditions obtained on oxidation.

Many satisfactory methods have been developed for the removal of hydrogen sulphide from hydrocarbon gases. All these methods depend on absorption of the hydrogen sulphide in a weakly alkaline solution followed by regeneration of the absorbing solution, usually by heating.

The regeneration process produces a gas which is relatively rich in hydrogen sulphide, and it is generally most useful to oxidise this to either sulphur or sulphuric acid. The difficulty with direction conversion to sulphuric lies in the fact that the combustion produces a wet SO_2 gas which must either be dried carefully before conversion or be converted in a special wet-gas contact plant and, in general, unless strong acid from sulphur is available, the acid produced will require concentration.

It is generally most economical and most advantageous to convert the hydrogen sulphide to sulphur, and recovery of sulphur from hydrogen sulphide has, in fact, been practised for some considerable time.

One of the earliest processes for this conversion was the Claus process, in which the hydrogen sulphide was catalytically oxidised to sulphur in a reactor kiln packed with bog iron ore. This reaction was maintained at a low temperature to avoid conversion of sulphur to sulphur dioxide. The expected reaction would then be:

$$H_2S + \tfrac{1}{2} O_2 \rightarrow S + H_2O \quad \ldots\ldots\ldots\ldots\ldots (1)$$

and the low throughput and efficiency could be directly attributed to the difficulty in maintaining this relatively low temperature.

The modifications developed by I. G. Farbenindustrie and Baehr depended on recovery of sulphur by contact catalytic conversion of hydrogen sulphide with the sulphur dioxide resulting from the partial combustion of the hydrogen sulphide, generally in accordance with the equations:

$$H_2S + \tfrac{3}{2} O_2 \longrightarrow SO_2 + H_2O \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$2H_2S + SO_2 \longrightarrow 3S + 2H_2O \quad \ldots\ldots\ldots\ldots\ldots (3)$$

This Baehr-Claus process has been generally adopted for the recovery of sulphur from the hydrogen sulphide in petroleum crude.

Another source of rich hydrogen sulphide gas is in the manufacture of carbon disulphide made by the retort process, where the hydrogen sulphide is unavoidably formed by reaction between moisture adsorbed in the charcoal and molten sulphur.

This hydrogen sulphide gas represents a serious sulphur wastage and also under the normal statutory regulations cannot be discharged directly into the atmosphere and must be converted to sulphuric acid, sulphur or, by adsorption in oxide trays, for further conversion to acid by combustion of the spent oxide resulting.

The Baehr-Claus process provides the most efficient process for the conversion to sulphur of this rich gas and has been generally adopted by the industry, the flow sheet being generally in accordance with that shown in Fig. 1, the reactions being a combination of equations (1), (2) and (3).

In the combustion chamber, hydrogen sulphide is burnt with an insufficiency of air, thus:

$$2H_2S + 2O_2 \longrightarrow S + SO_2 + 2H_2O$$

Catalytic conversion of the remaining H_2S then takes place, with the SO_2 produced in accordance with equation (3).

To give the maximum recovery of sulphur it is usual to operate with two catalytic converters in series, the recovery of sulphur taking place by means of sulphur gas cooler scrubbers at the outlets of the catalytic converters, and some design details have been given[1] for the construction of such a sulphur scrubbing tower.

Table 1. Material to sulphur scrubber and gas cooling tower

Inlet gas temperature = 600°F.
Outlet gas temperature = 270°F.
Liquid sulphur inlet temperature = 250°F.
Liquid sulphur outlet temperature = 318°F.

Gas	*Lb./hr.*	*MW*	*Mol.*	*Cu.ft./hr.*	*Vol.*, %
H_2S	1,113	34	32.8	12,250	2.5
SO_2	1,046	64	16.3	6,126	1.24
H_2O	7,950	18	442.0	167,000	33.7
N_2	22,430	28	801.0	303,000	61.3
S vapour	3,050	192	15.9	5,390	1.26
	35,589		1,308.0	493,766	100

Average *MW* of gas = 27.2
Sulphur remaining in the outlet gas = 2.3 lb./hr.
= 0.16 mol.
= 45 cu.ft./hr.
Latent heat of vaporisation of sulphur = 1,140 B.T.U./lb.

Consideration is given in Table 1 to a basis for a plant design for such a gas cooling tower as used on a carbon disulphide gas recovery plant.

Thermal conductivity of gas (k) = 0.0181 at 212°F., and is extrapolated to the required temperature by means of the relationship log $k \propto$ log T.

Diffusion coefficient D for the diffusion of sulphur vapour through the gas is determined by the use of Arnold's equation:

$$D_g = \frac{0.00837\ T^{\frac{1}{2}}}{p(V_A^{\frac{1}{3}} + V_B^{\frac{1}{3}})^2(T + C_{AB})}\sqrt{\frac{1}{M_A} + \frac{1}{M_B}} \quad \text{sq.cm./sec.}$$

where $C_{AB} = \left(\frac{2\sqrt{V_A^{\frac{1}{3}}\ V_B^{\frac{1}{3}}}}{V_A^{\frac{1}{3}} - V_B^{\frac{1}{3}}}\right)^3 \sqrt{C_A\ C_B}$

C_A C_B are constants for the gas and sulphur vapour respectively and can be estimated from the relationship

$$C = 1.47\ T_b$$

where T_b is the normal $B\ P_t$ in °K.

Using this correlation D_g = 1.68 sq.ft./hr. at 430°F., the mid-tower temperature is set out in Tables 2 and 3.

Table 2. Vapour pressure/temperature of sulphur

Pressure/mm. Hg	*Temperature*, °F.
1	363
5	434
10	470
20	506.6
40	551
60	582.5
100	621
200	679.5
400	751
760	830

Table 3. Viscosity/temperature of liquid sulphur

Viscosity in centipoises	*Temperature*, °F.	
10.94	253	Range of liquid sulphur temperature 250° to 318°F. Average = 10 cp.
8.66	275	
7.09	300	
7.19	313	
7.59	316	
9.48	317.8	
14.45	318.34	
22.83	319.74	
77.32	319.74	

Specific heat sulphur vapour at 600°F. = 0.138 B.T.U./lb.
Specific heat liquid sulphur at 275°F. = 0.22 B.T.U./lb.
Melting point of sulphur = 235°F.
Latent heat of vaporisation at 1 atm. = 1,140 B.T.U./lb.

Calculation of Lewis number at 435°F.

$$Le = \left(\frac{k}{C_s \rho D_g}\right)^{\frac{2}{3}} =$$

$$\left(\frac{\text{Thermal conductivity}}{\text{Humid sp. heat} \times \text{gas diffusion coefficient} \times \text{density}}\right)^{\frac{2}{3}}$$

$$= \left(\frac{0.0132}{0.257 \times 0.042 \times 1.68}\right)^{\frac{2}{3}} = (0.87)^{\frac{2}{3}} = 0.4169$$

Sutherland's formula is used for determination of the change of viscosity with temperature:

$$\frac{\mu}{\mu_o} = \frac{273 + C}{T + C}\left(\frac{T}{273}\right)^{\frac{3}{2}}$$

μ = viscosity of gas at temperature T
μ_o = viscosity of gas at temperature 273°K.
C is a constant for the gas = 110.

Also for variation of diffusivity with temperature the following relationship proposed by Sutherland was used:

$$\frac{D}{D_o} = \frac{273 + C}{T + C}\left(\frac{T}{273}\right)^{\frac{5}{2}}$$

The partial pressure of sulphur in the gas entering the tower is:

$$\frac{760 \times 1.26}{100} = 9.6 \text{ mm.}$$

Therefore the dewpoint is 470°F.

Partial pressure of sulphur in the gas leaving lower = 0.097 mm. Then saturation at inlet is:

$$\frac{9.6}{750.4} \times \frac{192}{27.2} = 0.09 \text{ lb./lb. dry gas}$$

$$\text{At outlet} = \frac{23}{32{,}540} = 0.00071 \text{ lb./lb.}$$

Then $\Delta H_g = 0.09 - 0.00071 = 0.0893$ lb.

$$\text{Specific heat of cooled gas} = \frac{0.24 \times 29}{27.2} = 0.256 \text{ B.T.U./lb.}$$

Enthalpy of gas at inlet: B

$$i_2 = 1{,}140\ (0.09) + (600 - 32)\ [0.256 + 0.14\ (0.09)]$$
$$102.5 + 153 = 254.5 \text{ B.T.U./lb.}$$

Outlet enthalpy is:

$$i_2 = 1{,}140\ (0.00071) + (270 - 32)\ [0.256 + 0.14\ (0.00071)]$$
$$0.8 + 60 = 60.8 \text{ B.T.U./lb.}$$

Saturation enthalpies

Inlet $i_2^\star = 102.5 + 438\ (0.2686) = 218.5$ B.T.U./lb.
Outlet $i_1^\star = 0.8 + 54.8 = 55.6$ B.T.U./lb.
$\Delta i = 254.5 - 60.8 = 193.7$ B.T.U./lb.

If L is the rate of liquid sulphur entering the tower in lb./hr., then on 1 lb. dry gas basis the sulphur/gas ratio at the bottom of the tower is given by:

$$\left(\frac{L}{G} + 0.09\right)(318 - 32) - \frac{L}{G}(250 - 32)$$

$$= \frac{193.7}{\text{Specific heat of sulphur}}$$

$$286\ \frac{L}{G} + 25.8 - 318\ \frac{L}{G} = \frac{193.7}{0.22}$$

$$68\ \frac{L}{G} = 880 - 25.8 = 854.2$$

$$\frac{L}{G} = 12.675 \text{ lb./lb.}$$

The sulphur pick-up is relatively small, so that this can be assumed constant throughout the tower.

Area of cross-section

For the 1-in. steel or aluminium grids (1 in. pitch × 1 in. deep × ¼ in. thick) selected for the tower packing the specific surface is $a_v = 24$ sq.ft./cu.ft., and the fraction of void space = 0.75 cu.ft./cu.ft. The mean liquid sulphur viscosity is 10 centipoises (Fig. 2).

The flooding point is found by use of the generalised Lobo correlation.

$$\text{The term } \frac{L}{G}\sqrt{\frac{\rho}{\rho L}} = 12.675\sqrt{\frac{27.2}{359}\ \frac{492}{890}\ \frac{1}{124.8}} = 0.21$$

Corresponding ordinate = 0.068

Then gas flooding rate:

$$G_F = \sqrt{\frac{(0.068)\ (0.042)\ (124.8)\ (4.17 \times 10^8)\ (0.75)^3}{24\ (10)^{0.2}}}$$

$$= \sqrt{\frac{(0.10)\ (0.042)\ (124.8)\ (4.17 \times 10^8)\ (0.422)}{24\ (1.585)}}$$

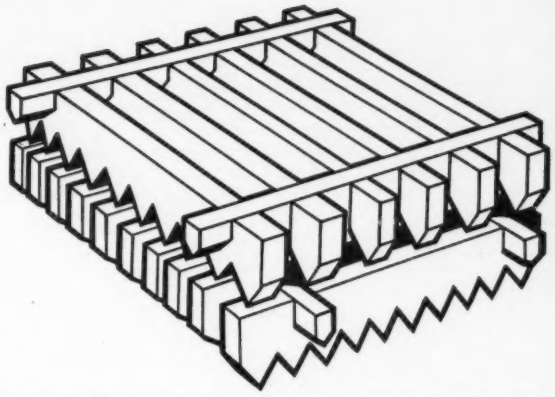

Fig. 2. Grid packing for sulphur tower in aluminium. For film flow notches should direct liquid to top edges of next lower layer without splashing

$G_F = 1{,}020$ lb./hr.sq.ft.

Actual flow rate used = 510 lb./hr.

$$\%\ \text{flooding} = \frac{510}{1{,}020} = 50\%$$

Gas film mass transfer coefficient

An equation for the gas film coefficient in a packed tower at a given relative velocity has been developed by Morris and Jackson[9, 10] and is given as follows:

k_g = Packing factor × coefficient in 1-in.-diam. falling-film tower

$$k_g = 2.28\ RC\ V^{0.75}\left(\frac{1}{P^{0.25}}\right)$$

where R = enhancement factor = 1.8 for grids
V = relative velocity = $V_g + V_L$
V_g = mean linear velocity through packing = $\frac{V}{\varepsilon}$ ft./sec.
V_L = liquid surface velocity = 0.5 ft./sec.
P = total pressure, atm.
C = constant = $\left(\frac{\rho_r}{\mu_r}\right)^{0.25}(D_g)^{0.5}$ all in ft./cm./sec.

$$V_g = \frac{510}{0.042 \times 3{,}600} = 3.37 \text{ ft./sec.}$$

$V = 3.87$ ft./sec.
$C = 0.69$
$k_g = 2.28 \times 1.8\ (3.37)^{0.75} \times 0.69$
$= 2.28 \times 1.8 \times 2.477 \times 0.69 = 7$ lb./hr.sq.ft. atm.

$$\text{Transfer area } A = \frac{G}{k_g}\ \frac{M_s}{M_g}\ \frac{(i_2 - i_1)}{(i)_m}$$

$i_2 - i_2^\star = 254.5 - 218.5 = 36$
$i_1 - i_1^\star = 60.8 - 55.6 = 5.2$

$$(i)_m = \frac{36 - 5.2}{2.3 \log 36/5.2} = \frac{30.8}{2.3 \times 0.7716} = 17.4$$

$$A = \frac{35.589}{7}\ \frac{192}{27.2}\ \frac{193.7}{17.4}$$

$$= 40{,}000 \text{ sq. ft.}$$

$$\text{Height of tower} = \frac{40{,}000}{24 \times 64} = 26 \text{ ft.}$$

The above is a simplified method using a Lewis number for air/water vapour equal to unity. In the present case this is not correct and an incremental method must be used with the correct derived value of the Lewis number.

Having obtained L, the liquid rate, the quantity of sulphur diffused in the tower and the quantity of heat transferred can be determined by $K_x a\ V/L$ or $h\ aV/L$, both of which are related by the ratio

$$\left(\frac{k}{C\rho D}\right)^{\frac{2}{3}} = Le$$

which varies with the temperature in the tower.

Direct contact sulphur scrubber

Calculations of direct contact sulphur scrubber gas cooler can be done by incremental trial and error method.

The gas loading is as previously given, 35,589 lb./hr. and, at the economical gas rate of 50% of flooding velocity, the cross-sectional area is 64 sq. ft., utilising for simplicity of construction an 8 ft. × 8 ft. tower.

At the gas inlet saturation = 0.09 lb./lb. dry gas
Sulphur in inlet gas = 3,050 lb./hr.
Gas inlet temperature = 600°F. Dewpoint = 470°F.
Saturation of outlet gas = 0.00071 lb./lb.
Gas outlet temperature = 270°F. Dewpoint = 224°F.
Total heat load = $G\ (i_2 - i_1)$ = 35,589 (193.7)
= 6,890,000 B.T.U./hr.

$L.\ c_L\ (t_1 - t_2) = G(i_2 - i_1)$
$L.\ 0.22\ (318 - 250) = L.\ 15 = 6{,}890{,}000$

$$L = \frac{6{,}890{,}000}{15} = 460{,}000 \text{ lb./hr.}$$

Taking incremental values for diffusion units = 0.1 diffusion unit, and working from the base of the tower upwards, the assumed inlet sulphur temperature should coincide with that arrived at by this stepwise procedure. If these do not coincide, the assumed temperatures and saturations are incorrect and a more accurate answer can be obtained by a further trial and error approximation until the coincidence is obtained.

Interval 1

$$K_x\ a\frac{\Delta V}{L} = 0.1$$

$$\frac{K}{C_p\ D}^{\frac{2}{3}} = 0.4169$$

$$C_s = 0.256 + 0.138 \times 0.09$$
$$= 0.2684 \text{ B.T.U./lb.°F.}$$

$$haV = K_x\ a\ \frac{V}{L}\ (Le)^{\frac{2}{3}}\ C_s$$

$$= 0.1 \times 460{,}000 \times 0.4169 \times 0.2684$$
$$= 2{,}460 \text{ B.T.U.}$$

$$q = 2{,}460\ (600 - 318) = 695{,}000 \text{ B.T.U.}$$

$$\Delta t = \frac{695{,}000}{0.2684 \times 35.589} = 72.5°\text{F.}$$

$$T_{0.1} = 600 - 72.5 = 527.5°\text{F.}$$

$$\Delta t = \frac{695{,}000}{0.22 \times 460{,}000} = 6.88°\text{F.}$$

$$t_{0.1} = 318 - 6.88 = 311.12$$

Interval 2

$$q = 2{,}460\ (527.5 - 311.12) = 530{,}000 \text{ B.T.U.}$$

$$\Delta t = \frac{530{,}000}{0.2684 \times 35{,}589} = 55.5°\text{F.}$$

$$T_{0.2} = 527.55 - 55.5 = 472°\text{F.}$$

$$\Delta t = \frac{530{,}000}{0.22 \times 460{,}000} = 5.25°\text{F.}$$

$$t_{0.2} = 311.12 - 5.25 = 305.87°\text{F.}$$

Interval 3

$$q = 2{,}460\ (472 - 305.87) = 410{,}000 \text{ B.T.U.}$$

$$\Delta t = \frac{410{,}000}{0.2684 \times 35{,}589} = 42.8°\text{F.}$$

$$T_{0.3} = 472 - 42.8 = 429.2°\text{F.}$$

$$\text{At } 429.2°\text{F. } H = \frac{5}{755} \times \frac{192}{27.2} = 0.0468 \text{ lb./lb.}$$

Sulphur diffusing $0.1 \times 460{,}000 \times 0.0432 = 1{,}980$ lb.
Sulphur remaining $1{,}070 = 3{,}050 = 0.03$ lb./lb.

$$q_d = 1{,}980 \times 1{,}140 = 2{,}250{,}000$$
$$q = 2{,}660{,}000$$

$$t_{0.3} = \frac{2{,}660{,}000}{0.22 \times 460{,}000} = 26.4°\text{F.}$$

$$= 305.87 - 26.4 = 279.47°\text{F.}$$

Interval 4

$$q = 2{,}460\ (429.2 - 279.47) = 367{,}000 \text{ B.T.U.}$$

$$\Delta t = \frac{367{,}000}{0.2684 \times 35{,}589} = 38.5°\text{F.}$$

$$T_{0.4} = 429.2 - 38.5 = 390.7°\text{F.}$$
$$H \text{ at } 390.7°\text{F.} = 0.00278 \text{ lb./lb.}$$

Sulphur diffusing $= 0.1 \times 460{,}000 \times 0.0405 = 1{,}047$ lb.
Sulphur remaining = 23 lb.

$$q_d = 1{,}190{,}000$$
$$q = 1{,}557{,}000$$

$$t_{0.4} = \frac{1{,}557{,}000}{0.22 \times 460{,}000} = 15.4°\text{F.}$$

$$= 279.47 - 15.4 = 264.07°\text{F.}$$

Interval 5

$$q = 2{,}460\ (390.7 - 264.07)$$
$$= 2{,}460 \times 126.63 = 310{,}000 \text{ B.T.U.}$$

$$\Delta t = \frac{310{,}000}{0.267 \times 35{,}589} = 32.6°\text{F.}$$

$$T_{0.5} = 390.7 - 32.6 = 358.1$$

Diffusion negligible

$$\Delta t_{0.5} = \frac{310{,}000}{0.22 \times 460{,}000} = 3.07°\text{F.}$$

$$t_{0.5} = 264.07°\text{F.} - 3.07 = 261$$

Interval 6

$$q = 2{,}460\ (358.1 - 261) = 240{,}000$$

$$\Delta t = \frac{240{,}000}{0.267 \times 35{,}589} = 25.5°\text{F.}$$

$$T_{0.6} = 358 - 25.5 = 332.5$$

$$\Delta t_{0.6} = \frac{240{,}000}{0.22 \times 460{,}000} = 2.5°\text{F.}$$

$$t_{0.6} = 261 - 2.5 = 258.5°\text{F.}$$

Interval 7

$$q = 2{,}460\ (332.5 - 258.5) = 182{,}000 \text{ B.T.U.}$$

$$t = \frac{182{,}000}{0.267 \times 35{,}589} = 19.2°\text{F.}$$

$$T_{0.7} = 332.5 - 19.2 = 313.3°\text{F.}$$

$$t_{0.7} = 258.5 - 1.81 = 256.69°\text{F.}$$

Interval 8

$$q = 2{,}460\ (313.3 - 256.7) = 2{,}460\ (56.6)$$

$$\Delta t = \frac{140{,}000}{0.267 - 35{,}589} = 14.8°\text{F.}$$

$$T_{0.8} = 313.3 - 14.8 = 298.5$$

$$\Delta t_{0.8} = \frac{140{,}000}{0.22 \times 46{,}000} = 1.4°\text{F.}$$

$$t_{0.8} = 256.61 - 1.4 = 255.29°\text{F.}$$

Table 4

Interval	$K_x a \frac{V}{L}$	T °F.	t °F.	*S diff. in lb.*	q_c B.T.U./hr.	q_d B.T.U./hr.
	0	600	318			
1	0.1	527.5	311.1	—	695,000	—
2	0.2	472	305.8	—	530,000	—
3	0.3	429.2	279.5	1,980	410,000	2,250,000
4	0.4	390.7	264	1,047	367,000	1,190,000
5	0.5	358	261	—	310,000	—
6	0.6	332.5	258	—	240,000	—
7	0.7	313	256.7	—	182,000	—
8	0.8	298.5	255.3	—	140,000	—
9	0.9	296	254	—	138,000	—
10	1.0	284	252.5	—	135,000	—
11	1.15	270	250	—	200,000	—
					3,457,000	3,440,000

$\therefore q = 6{,}897{,}000$ B.T.U./hr.

Number of diffusion units $= n_d = 1.15$

Then tower height $Z = \frac{n_d \cdot L \cdot c_s}{K_x \cdot a_v \cdot A} = 21.3$ ft.

$$= \frac{1.15 \times 460{,}000 \times 0.22 \times 32}{7 \times 24 \times 64 \times 27.2} = 14.5 \text{ ft.}$$

Since $K_x = \frac{K_g \times M_{gas}}{M_{liquid}}$, M = mol. wt. of sulphur

This demonstrates that the approximate method of cooling tower design errs considerably on the safe side whenever the value of the Lewis number is much below unity. Conservative practice in this case would indicate a mean height to be used

$$= \frac{14.5 + 26}{2} = 20.25 \text{ ft.}$$

Say, 20 ft. of grid packing used in the cooling tower.

The construction of the sulphur scrubber cooling tower was as follows, and as illustrated in Fig. 3.

The shell consisted of mild-steel sheet welded on to a structural steel frame, the tower being made square in section (8 ft. × 8 ft.). Normal film tower packing was used for fill, either fabricated into grids from mild steel or in ¼-in.-thick aluminium, and packed in staggered horizontal rows.

Liquid sulphur is pumped over the tower packing with

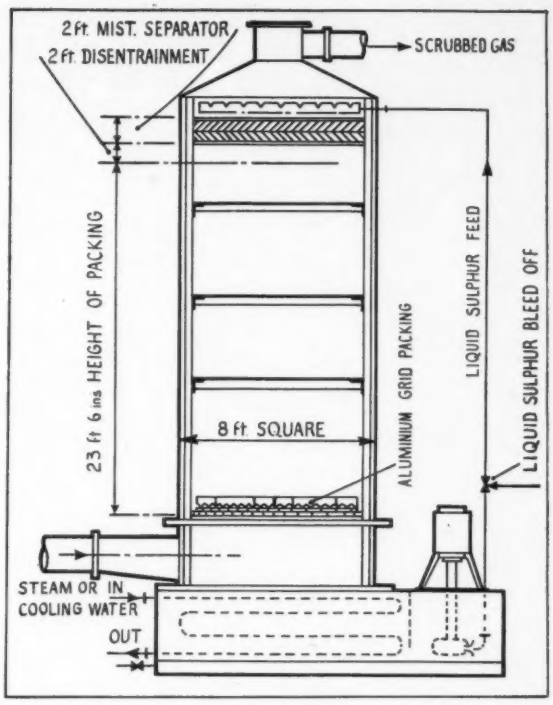

Fig. 3. Arrangement of sulphur scrub tower

a submerged centrifugal pump in cast-iron fitting in the sulphur pit, as shown.

Because of the extremely rapid change of viscosity of sulphur with temperature, the melting pit is fitted with a coil for either steam or water and the temperature is maintained constant at 250° ± 5°F. by thermostatic control on this coil.

The product sulphur can be drawn off the pit by a bleed-off valve in the liquid sulphur pump discharge line.

The second part of this article will be appearing in the February issue of CHEMICAL & PROCESS ENGINEERING

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Sir Alexander Fleck opening the Exhibition

The Ceaseless Struggle Against Corrosion

The world's largest Exhibition of its kind devoted to corrosion and metal finishing, sponsored by CORROSION TECHNOLOGY, was held at the Empire Hall, Olympia, from November 29 to December 2. Many visitors from all parts of the world showed keen interest in the latest developments in the war against corrosion. In addition there were two symposia during the Exhibition, one organised by the Plastics Institute and the other by the Corrosion Group of the Society of Chemical Industry.

THE vital importance of battling against corrosion was vividly demonstrated by the attendance of thousands of visitors, representatives of every branch of industry, who flocked to Olympia from November 29 to December 2 to see for themselves the latest products and services of the anti-corrosion and metal-finishing industries. The climate of Great Britain, combined with the dense industrial areas and fuel habits, make it one of the countries most prone to corrosion in the whole world. The annual cost of corrosion, which has often been estimated at around £600 million, is a sum that does not fall far short of the yearly cost of the National Health Service. It can rightly be argued that corrosion is a malady, as ubiquitous and menacing as the ills that afflict the human body, and this is particularly so in the chemical industry. Indeed, it was not until chemical manufacturers began to realise the importance of selecting proper materials of construction for chemical plant, primarily to resist corrosion, that modern chemical engineering began.

Sir Alexander Fleck, K.B.E., F.R.S., president of the Society of Chemical Industry, gave the opening address. The following is a short extract of Sir Alexander's speech:

'I take it as a great compliment to be asked to open this Exhibition, the Corrosion and Metal Finishing Exhibition. Additionally, I regard the occasion as one on which the president of the Society of Chemical Industry, who happens at this time to be myself, can very usefully and indeed very appropriately take a great interest.

'The scientific societies exist to promote and diffuse knowledge, which they do by the organisation of meetings for the reading and discussion of papers. It is no part of the role of a scientific society to organise an exhibition, any more than it is appropriate for the organisers of an exhibition to arrange scientific conferences. It is, therefore, very natural in such circumstances that a marriage should be arranged between the Corrosion Group of the Society and the organisers of the Exhibition so that we have the best of both worlds—a fine Exhibition and a good conference. I hope that this is an omen and that we shall see the precedent here established repeated on many suitable occasions.

Mr. W. Leonard Hill, Chairman, Leonard Hill Technical Group, speaking at the Exhibition dinner

'The very high cost of corrosion is also good justification for the logical step, taken this year for the first time, of inserting "Metal Finishing" into the title of the Exhibition. We are all sufficiently practical people to agree that study of corrosion alone, no matter how wise it is to do so, is not enough; it should be followed up by

practical steps to do what we can to prevent, and that is where metal finishing obviously comes into this particular picture.

Electrochemical reaction

'Corrosion of metals in our modern terminology is accepted as basically an electrochemical phenomenon and I do not think any student of corrosion could hope to make much progress in its scientific examination and explanation if he were not a very thoroughly equipped electro-chemist. That, however, does not alter the fact that there are many opportunities still in our corrosion studies for empirical practices for very useful development in dealing with corrosion problems. The development of numbers of stainless steels might be regarded as examples of this type of progress. In the chemical industry, I think above all others, we are appreciative of the usefulness of the stainless steels. By their early help, we were able to get away from brick-lined towers for nitric acid and that enabled most substantial advances to be made. In the fullness of time, stainless-steel welding became a normal technique which again facilitated the manufacture of quite sophisticated pieces of apparatus.

'It is not a new question to ask—I think Sir Owen Wansbrough Jones asked it last year—"When we know that corrosion is such an active process is it not possible to enlist it for an ally?" I know that in asking this question in this form I am getting on to ground that is not very firm. Under some definitions, electrolytic refining involves corrosion. Electrolytic etching and the procedures known as chemical milling are in the same category. Those, however, are very specialised uses of the word corrosion, where appreciable quantities of electrolyte are present to dominate the reaction and its speed.

'This, I gather, is but the fourth year of this Exhibition. That over these years it has shown steady growth is good evidence of proof that it is fulfilling a real need in our technological activities and, on declaring this Exhibition worthily conceived and now officially opened, I wish it every success — success both to the Exhibition as a whole and to the individual exhibitors who are contributing. To them again there are good wishes for their exhibit here and for the success and effectiveness of their products in the hard outside world of practical application to the problem of corrosion and its prevention'.

Technical meetings

There were two symposia during the Exhibition, one organised by the Plastics Institute and the other by the Corrosion Group of the Society of Chemical Industry. The following papers were presented at these symposia:

PLASTICS INSTITUTE SYMPOSIUM

- Protective Packaging — Engineering Applications, by D. Gonda
- Plastics as Heavy Protective Coatings, by N. Vinson, Plastic Coatings Ltd.
- Fabricated Plastics and their Role in Combating Corrosion, by D. W. Shorton

SOCIETY OF CHEMICAL INDUSTRY, CORROSION GROUP SYMPOSIUM

- The Influence of Water Movement on Corrosion—Ferrous Materials, by Dr. R. Butler
- The Influence of Water Movement on Corrosion — Non-ferrous Metals, by Dr. N. V. Nowlan

Altogether there were 94 exhibitors representing all types of industries connected with corrosion prevention. Some exhibits of particular interest from the chemical engineering point of view are outlined below.

Highly resistant heat exchanger

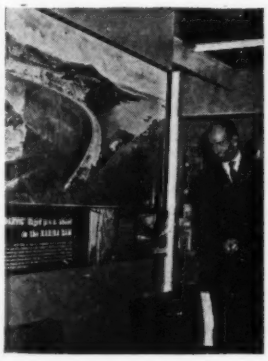
A new type of highly resistant heat exchanger was on show at the I.C.I. stand. The design features provide for only titanium tubing and PVC to be in contact with chemicals and, by removing the PVC connections, an easy visual inspection of the tubes can be made. The overall length of the exchanger is 8 ft. 6 in.

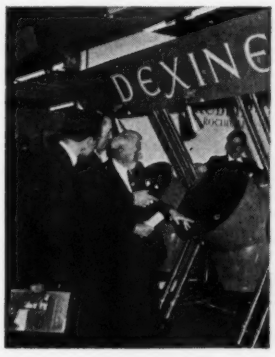
As an example of its efficiency the heat exchanger can raise the temperature from 50° to 140°F. in 150 min. with a steam pressure of 30 p.s.i. at a liquid flow of 500 gal./hr., the vat capacity being 500 gal. This corresponds to a heat input of 2,244,000 B.T.U./hr. The main uses for this heat exchanger are for commonly used nickel plating solutions, straight chromium plating solutions and various other metal finishing liquors.

Coal-bunker linings

Visitors to the Dunlop stand noticed a model coal bunker which was lined with glass; this is claimed to solve problems that exist in collieries, power stations and locations where finely divided coal is stored in bunkers. Increased mechanisation in the collieries has resulted in the production of more and more fine coal. The bunkers are normally constructed from either steel or reinforced concrete. The ideal bunker lining would comprise a corrosion-resistant material having a smooth surface over which the coal could flow freely. Glass is such a material and by the use of latex/cement compounds a method of adhering the glass to either steel or concrete was devised.

The first contract for this type of equipment was carried out some nine or ten years ago and proved to be completely successful. Not only does the latex/cement provide the required adhesion, but it also possesses resistance to corrosive conditions which are likely to obtain, as well as sufficient





Some of the stands and visitors

flexibility to accommodate movement within the bunker structure.

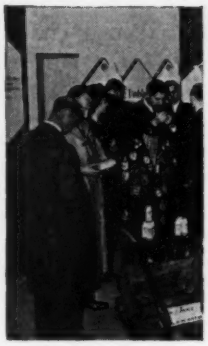
Protection of uranium

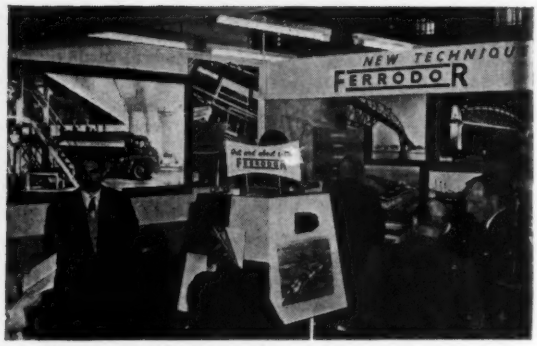
The display on the stand of the Atomic Weapons Research Establishment dealt with the corrosion of uranium and plutonium. Uranium rapidly tarnishes in air to form a brownish monoxide film. Protection of metals from oxidation and corrosion is most frequently achieved by applying electrochemically a coating of another metal more resistant to the environment. In the atomic energy industry the metals requiring protection are sometimes those which, on account of their reactive nature, are more successfully plated by dry methods.

While uranium can be electroplated by wet electrolytic processes, coatings thus obtained are seldom strongly adherent and they tend to blister when attempts are made to improve the adhesion. Poor protection often results because the attack is not localised at any point but spreads rapidly along the interface. In a search for a dry method of plating it is difficult to find a technique which can yield coatings that are ductile, non-porous and can be applied uniformly to a considerable thickness.

Extensive development of a technique for the deposition of nickel from the carbonyl has been carried out at A.W.R.E. and it may now be regarded as a satisfactory production process. Thick ductile coatings of uniform thickness have been obtained, and the technique has been proved to be highly successful for coating metals that are reactive towards moisture. Coatings of 5×10^{-3} in. thickness, applied to uranium, proved markedly superior to coatings applied by electroplating. Diffusion bonding at 600° to 650°C. after plating ensures a firmly adherent coating.

The highly protective quality of the nickel carbonyl coatings was illustrated by two experiments on display. In one experiment the specimens were heated to 500°C. in air and in the other they were immersed in boiling water. In each case a comparison was made between three uranium specimens, one with a nickel coating obtained by the carbonyl process, a second with a coating obtained by electroplating, and a third unprotected.





More of the exhibitors' stands

Metal treatment

The Pyrene Co. exhibits demonstrated the *Bonderizing* process which covers a range of processes for the treatment of iron, steel, aluminium, zinc and cadmium surfaces. The treatment is normally carried out in a hot solution; this converts the surface of the metal into a non-metallic phosphate coating which, when painted, lacquered or enamelled, provides an effective corrosion inhibitor, prevents spread of corrosion beneath the paint from any damaged areas and provides an excellent key for all types of organic finishes.

For small articles such as metal sheets or panels, simple immersion by hand in the processing solution is satisfactory. However, where production requirements demand other methods, this treatment may be equally well carried out either with a semi- or fully-automatic system. In most cases, mild steel can be used for the manufacture of the processing tanks.

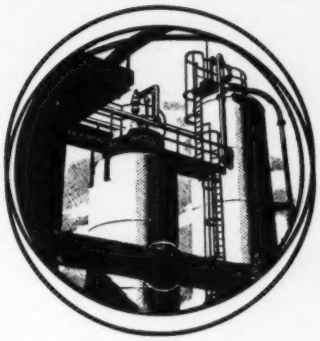
Mr. W. Leonard Hill (extreme left) next to Sir Alexander Fleck and Mr. W. G. Norris (second from right), the Director of the Exhibition, talking to the Schnakenberg exhibitors

Conclusions

The Exhibition can be described as an unqualified success. Personal reactions from individual exhibitors and visitors were extremely favourable. The most noticeable feature throughout the four days at Olympia was the seriousness with which every visitor viewed the various stands. Obviously many had come to Olympia in order to do business and the representatives manning the stands were all capable of supplying sufficient technical explanations to satisfy any potential client.

It is most encouraging that corrosion prevention is now receiving the full attention of industry, and it is complimentary to British industry that many countries throughout the world are turning to the U.K. for a lead in technological development in this field. The next Corrosion and Metal Finishing Exhibition, which will be held in 1962, will doubtlessly bring to light many more new processes which are now being developed.

Materials of Construction for Chemical Plant



PLATINUM

By J. A. Stevenson,* B.Sc.

This article, discussing the use of platinum and its alloys as materials of construction for chemical plant, is the ninth in this series. Previous articles have dealt with PVC, lead, nickel, stainless steels, graphite, polyolefines, copper and timber. The outstanding characteristic of platinum is its resistance to chemical attack, especially to oxidation in air at high temperatures. This property, together with its high melting point, is found of unique value in a number of specialised applications in chemical plant where corrosion and physical conditions are exceptionally severe.

PLATINUM is the dominant member of the 'platinum group of metals'; of the others, iridium, rhodium, ruthenium and osmium are mainly used as alloying additives to platinum, and the last member, palladium, finds its main outlets in the electrical industry and in the form of supported catalysts.

The six platinum metals occur together naturally either in chemical combination with sulphur, arsenic and antimony, or native, as alluvial deposits with gold or with iron and other base metals. Before the first world war, the bulk of these metals came from alluvial deposits in Russia and the Republic of Colombia, but since the discovery in South Africa and Canada of large deposits of platinum-bearing minerals these latter sources have provided by far the greatest part of the Western world's needs. Broadly similar deposits exist in Russia, and these are worked to provide supplies for the Soviet Union and its satellite countries.

In all three major producing countries the platinum metal content of the ores is small, and the processes of extraction are essentially methods of smelting and refining copper and nickel, followed by recovery, separation and refining of the platinum metals. South Africa differs from Canada and the U.S.S.R., however, in that its mines are worked primarily for platinum, yielding copper and nickel as by-products, whereas elsewhere the converse is true.

The South African output has grown very substantially and now constitutes the world's largest individual source of platinum.

Extraction and refining

Because of the very low platinum metals content of the ores, the extraction and refining processes are long and costly. Broadly speaking, they can be divided into five stages—ore dressing, smelting to give a copper-nickel matte, production of rough copper and nickel as anodes, electrolytic refining to produce anode 'slimes' rich in platinum metals, and wet chemical processing of these slimes to give the six metals in a high state of purity. Techniques for carrying out these stages naturally vary from one source to another, but it will be sufficient to describe as typical the processing to which the South African ores are subjected.

The dressing operations consist of crushing, milling, gravity concentration and oil flotation. These result in two products: high-grade gravity concentrates containing about 40% of platinum metals; and flotation concentrates consisting mainly of nickel, copper and iron sulphates, with about

Fig. 3. Pouring optical glass from a platinum crucible

* *Johnson, Matthey & Co. Ltd.*

10 oz./ton of platinum metals. The gravity concentrates are rich enough to be passed straight on for wet chemical treatment, but the flotation concentrate must be smelted and electro-refined. First they are mixed with slaked lime and flue dust and then briquetted. After drying, these briquettes are fed to a blast furnace with coke as fuel and smelted to a matte. This is then conveyed to a *Great Falls* converter and blown to a high-grade copper-nickel matte containing about 48% of nickel, 25% copper, and some 50 oz./ton of the platinum metals. At this point the matte is shipped to the refineries of Johnson, Matthey & Co. Ltd. in London where the rest of the processing is carried out.

Production of nickel and copper anodes begins with smelting of the South African matte in a blast furnace with salt cake. This is the *Orford* or ' tops and bottoms ' process and yields a copper sulphide-sodium sulphide ' tops ' containing most of the gold and silver and small amounts of the platinum metals, and a nickel sulphide ' bottoms ' containing most of the platinum metals. The ' tops ' are melted and blown in a *Pierce-Smith* converter to blister copper, conveyed to a reverberatory furnace for refining, and cast into anodes. These are electrolysed in an acid sulphate solution to produce copper cathodes and an anode residue containing gold, silver and platinum metals.

The nickel sulphide ' bottoms ' are ground and roasted in multi-hearth rotary furnaces to nickel oxide, which is briquetted with anthracite, reduced to metallic nickel in reverberatories and cast into anodes. These are electrolytically refined yielding nickel cathodes and leaving an anode residue containing the bulk of the platinum metals.

The residues from the two electrolytic refineries are then blended, roasted and acid-leached to remove the last traces of copper and nickel, finally yielding a concentrate containing about 60% of platinum metals.

Wet process refinery

At this point, these concentrates are joined by the gravity concentrates shipped from South Africa, and together they enter the wet process refinery. Here they are treated for complete elimination of unwanted metals, and the platinum metals brought into solution for their separation and individual refining. The metallic concentrates are digested with aqua regia, which dissolves most of the platinum and palladium and small amounts of the other metals of the group.

The insoluble residue is treated by fusion with oxidising fluxes, followed by distillation for the recovery of osmium and ruthenium, while iridium and rhodium are recovered from the residue liquors. The bulk of the platinum and palladium contained in the original aqua regia is freed from nitric acid, and separation and purification of the metals is effected through successive stages of crystallisation of their complex salts, which on calcination yield the metals in sponge form.

Routine production of platinum yields a metal of 99.99% purity. For special purposes, such as thermo-electric work, the sponge is double-refined to give a minimum of 99.999% purity. The other metals are also produced to the same order of purity.

Physical properties

Platinum, element 78, lies in the third long period in the periodic classification of elements, between iridium and gold, and below palladium. Its atomic weight is 195.23.

With a melting point of 1,769°C., platinum is particularly suitable for use in plant working at high temperatures. It has a face-centred cubic structure, and is easily worked. Alloys are readily formed with base metals and other members of the platinum group. This feature is of great importance in design work when it is often desirable to improve the mechanical properties and yet retain the high corrosion resistance. The important physical properties of platinum are given in Table 1.

Chemical properties

In the electrochemical series, the standard electrode potential of plati-

Fig. 10. Fitting a bursting disc assembly into a pipeline in a chemical plant

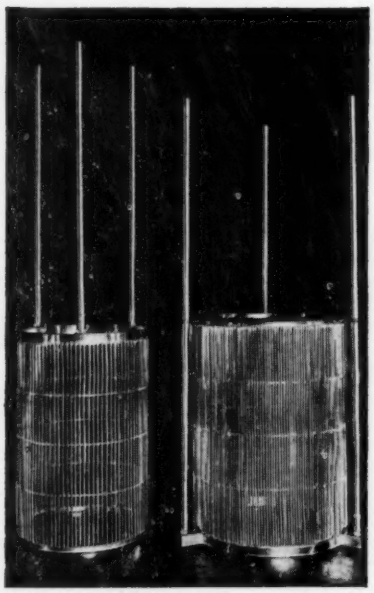


Fig. 8. A pair of large platinum electrodes for a special electrochemical process

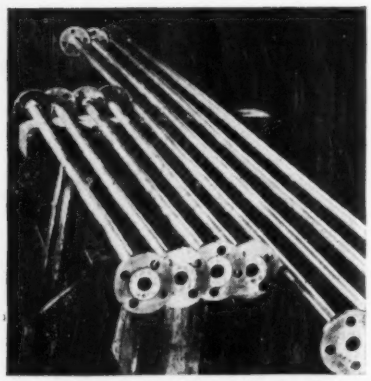


Fig. 9. Platinum-lined 'Inconel' tubes for use at high temperatures with corrosive gases

num is only exceeded by those of gold, iridium and rhodium. Its resistance to chemical attack does not depend on the formation of protective films, and it is stable in a very wide range of corrosive conditions even at high temperatures. Platinum is attacked by aqua regia, and by any other combination in which hydrochloric acid and chlorine are present in oxidising conditions. Apart from slight attack by hot concentrated sulphuric acid, the metal is virtually unaffected by other acids. It is also very resistant to alkalis, oxides and salts, but it can be attacked by fused caustic alkalis and by certain cyanides and peroxides at high temperatures. Organic reagents are generally without effect, except that catalytic activity in the presence of certain hydrocarbons may lead to surface etching.

Under normal conditions platinum remains free of oxide films at all temperatures, but above approximately 1,000°C. a volatile oxide forms. This results in a slight loss of weight, however the rate of volatilisation is extremely low.

Platinum combines readily with molten gold, silver and nearly all base metals, and with boron and silicon, so that reducible compounds of these elements should be heated in contact with platinum only under oxidising conditions.

Mechanical properties

Table 2 gives the main mechanical properties of platinum. These depend, of course, upon the condition and history of the specimen. By heavy cold working, the Vickers hardness can be increased from 40 in the annealed state to 120 to 125, and the tensile strength from 10 to about 15 tons/sq.in. Platinum retains some strength at elevated temperatures, tensile strength values of 2 to 3 tons/sq.in. being obtained at 1,000°C.

Nevertheless, even when work hardened, the metal is relatively weak for structural use, and in most applications must be backed by some more rigid material such as refractory brick or steel. Where such support is not possible, an alloy of platinum is used.

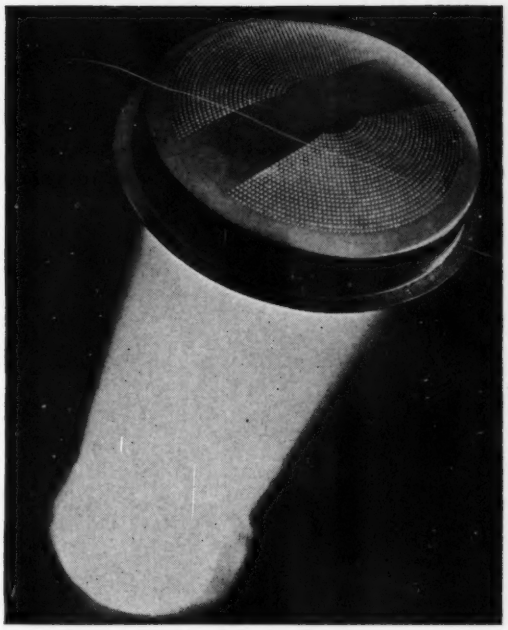


Fig. 7. This type of platinum jet has over 2,000 orifices and is made and used in the production of staple fibre by Courtaulds Ltd.

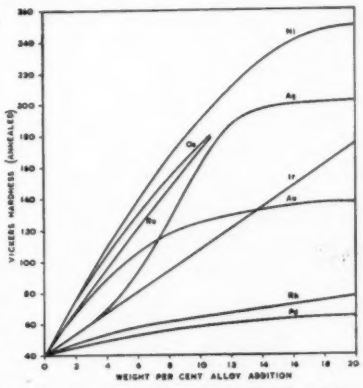


Fig. 1. Hardening effect of alloying additions on platinum

Principal alloys

For many applications greater hardness and strength may be required than are obtainable from pure platinum. Other metals of the platinum group are commonly used as alloying additions, since they help to retain the chemical nobility as well as improving the mechanical properties. Base metals such as molybdenum, tungsten, copper, nickel and cobalt are also used, but these alloys have their main applications in the electrical industry.

Fig. 1 shows the effect of alloying additions on the hardness of platinum, and the physical properties of the alloys commonly used in chemical engineering are shown in Table 3.

The rhodium-platinum group are the most important, combining good corrosion resistance with high creep strength at temperatures in excess of 1,000°C. Alloys containing up to 40% rhodium are readily fabricated, but with more than 40% they have little ductility and are almost unworkable.

For lower temperature work (below about 800°C.) the iridium-platinum alloys offer the best combination of high mechanical strength and good corrosion resistance. Alloys containing up to 20% iridium maintain the ductility and ease of working of pure platinum, but above 30% addition the alloy becomes extremely difficult to fabricate. When used at high temperatures, the iridium-platinum alloys lose weight due to the formation of volatile iridium oxide.

Additions of ruthenium to platinum

Table 1. Physical properties of platinum

Density, g./cc. at 20°C.	21.4
Melting point, °C.	1,769
Thermal conductivity, C.G.S. units	0.17
Specific heat, cal./g./°C. at 20°C.	0.032
Coefficient of linear expansion, (0° to 100°C.)/°C.	8.9×10^{-6}
Resistivity, microhm-cm. at 20°C.	10.6
Temperature coefficient of resistance, (0° to 100°C.)/°C.	0.00392
Thermal neutron absorption cross-section, barns	8.1

Table 2. Mechanical properties of platinum

Tensile strength, tons/sq.in. (annealed)	10
Limit of proportionality, tons/sq.in. (annealed)	2
Elongation, % (annealed)	40
Modulus of elasticity in tension, p.s.i.	22×10^6
Vickers hardness (annealed)	40

have a most marked effect upon both hardness and electrical properties, but the limit of workability is reached more quickly, occurring at about 15% ruthenium. Because of the tendency to produce a volatile oxide, ruthenium-platinum alloys are generally used in the lower-temperature ranges.

Gold-platinum alloys form a complex system of solid solutions, and are capable of being hardened by heat treatment. Their corrosion resistance is lower than the foregoing alloys, but for certain applications they are extremely useful.

Recently, grain-stabilised platinum and platinum alloys have become available. Pure platinum, like all pure metals, suffers from excessive grain growth when held for prolonged periods at high temperatures. The addition of a small amount of stable carbide or oxide in a finely dispersed form inhibits crystal growth and helps to retain the original fine structure. The effect of the additions is most marked in pure platinum, but some of the rhodium-platinum alloys are also treated to advantage.

Platinum in chemical plant

Records indicate that the first use of platinum in chemical plant dates from the early 1800s. In 1805, Wollaston produced a boiler for the concentration of dilute sulphuric acid yielded by the chamber process. The boilers had capacities up to 47 gal. each, and when first introduced they had to compete with glass retorts which were already well established.

Table 3. Physical properties of platinum alloys

Alloy	*Density, g./cc. at 20°C.*	*Melting point, °C. (solidus)*	*Resistivity, microhm-cm. at 20°C.*	*Temperature coefficient of resistance, (0° to 100°C.) /°C.*	*Ultimate tensile strength, tons/ sq.in.*	*Vickers hardness (annealed)*
5% Ir-Pt	21.5	1,780	19.6	0.0019	17	90
10% Ir-Pt	21.6	1,800	24.5	0.0013	24	120
20% Ir-Pt	21.7	1,815	32	0.00085	45	200
25% Ir-Pt	21.7	1,845	32.5	0.0008	48	240
30% Ir-Pt	21.8	1,885	33	0.0007	56	285
5% Ru-Pt	20.8	1,775	30	0.00096	26	135
10% Ru-Pt	19.9	1,780	42	0.00047	37	200
5% Rh-Pt	20.8	1,820	17	0.0021	16	60
10% Rh-Pt	20.0	1,850	18.4	0.0017	21	75
20% Rh-Pt	18.8	1,900	20	0.0014	27	90
40% Rh-Pt	16.8	1,950	17.5	0.0014	31	150

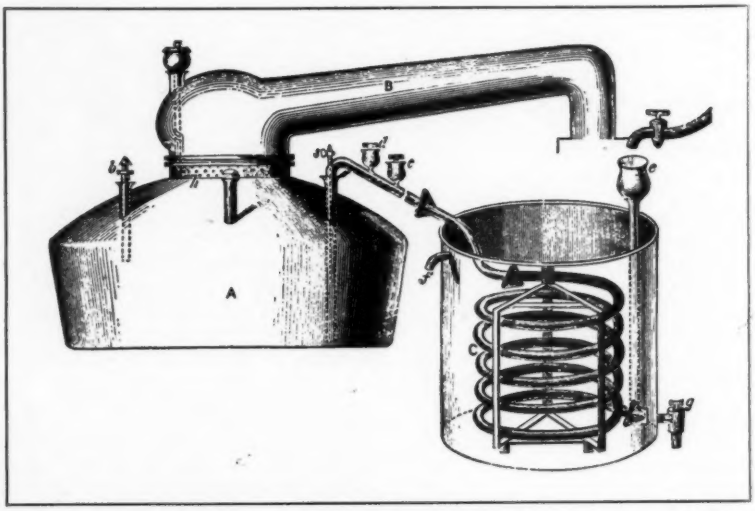


Fig. 2. A platinum boiler which had a capacity of 8 tons/day, exhibited by Johnson and Matthey at the Paris exhibition in 1867

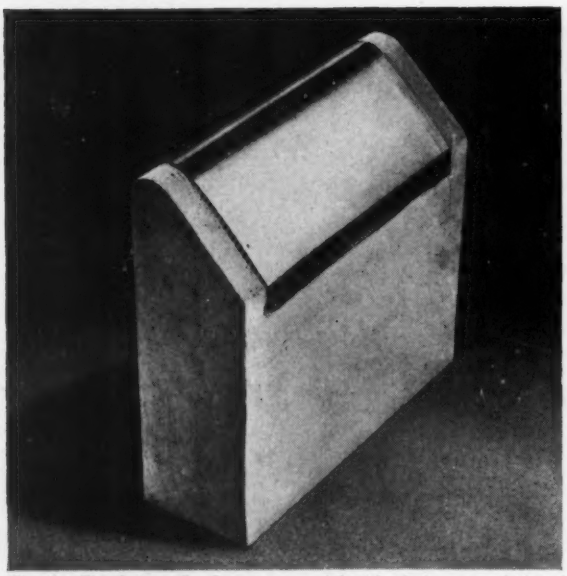


Fig. 4. The facing of refractory material with platinum or platinum alloy prevents erosion and contamination of the melt

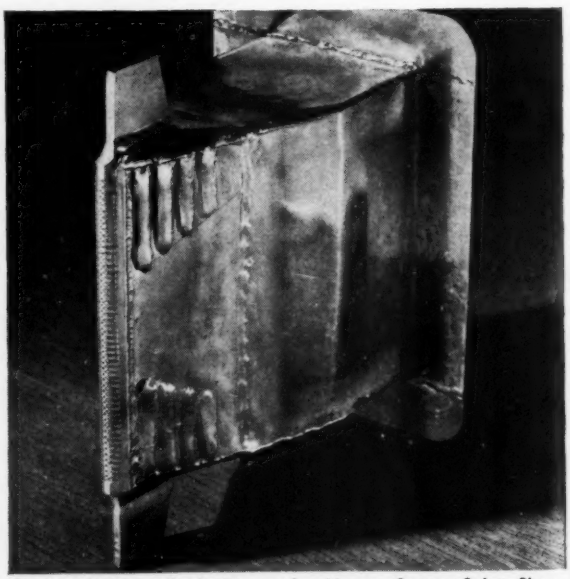


Fig. 5. A platinum alloy bushing employed in manufacture of glass-fibres. Orifices must retain their dimensions under continuous use up to 1,450°C.

Platinum, at that time, could only be melted and worked in small quantities, and so these early plants were constructed in segments with gold soldered joints. Leakages were not uncommon, and the vessels had a mixed reputation which was later improved when the technique for melting large quantities of platinum was developed.

A great advance came in 1861 when George Matthey, the junior partner in the London firm of Johnson and Matthey, discovered the technique of fusion welding platinum and this, for the first time, made a fully homogeneous joint possible.

Fig. 2 illustrates a boiler exhibited by Johnson, Matthey & Co. Ltd. at the Paris Exhibition in 1867, and platinum boilers continued to be used in the sulphuric acid industry until the introduction of the contact process at the turn of the century.

Today the glass industry is one of the largest users of platinum as a constructional material. As long ago as 1829, Faraday produced a number of optical glasses of exceptionally high purity by melting in platinum crucibles. On a larger scale this is still a standard method of producing high-quality optical or special glasses which are required to be free from iron oxide and other impurities. This is illustrated in Fig. 3.

Excessive attack of furnace refractories by molten glass can be prevented by sheathing the brickwork with sheets of platinum or rhodium-platinum. This is illustrated in Fig. 4, which shows a protected furnace skimmer block.

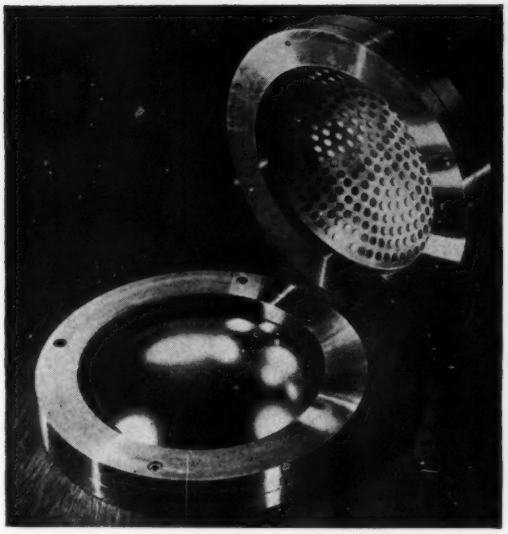


Fig. 11. Platinum bursting disc

In recent years the glass-fibre industry has become a major user of the rhodium-platinum alloys in the form of bushings. Basically, fibres are produced by drawing molten glass through fine orifices which are capable of retaining their dimensions when used continuously at temperatures up to 1,400°C.; 10% rhodium - platinum proved to be capable of withstanding these strenuous conditions, and Fig. 5 shows a typical bushing used for the production of fibre.

In more orthodox chemical engineering, platinum or platinum alloys are employed where extremely corrosive materials are to be handled, or where the purity of the end-product is of great importance.

Small pressure vessels are lined with comparatively thin platinum sheet while larger process equipment is made from platinum-clad nickel or copper as a means of reducing first cost. Typical applications of platinum-lined equipment include autoclaves for the manufacture of ethyl chloride and tubes for vapour-phase reactions with halogen acids at high temperatures.

In the preparation of plutonium metal from plutonium tetrafluoride, platinum again plays an important role. In the fluorination stage of the process a slurry of oxide is handled in platinum trays placed in batteries of electric furnaces into which anhydrous hydrogen fluoride gas is passed for several hours. These furnaces are lined with platinum, while the doors are kept as cool as possible by means of polished platinum reflecting shields mounted on their inner sides. This is shown in Fig. 6.

In the manufacture of artificial fibres, cellulose solution is forced through minute holes into an acid solution which coagulates it; this regenerated cellulose is then spun into yarn. The holes through which the viscose fluid is forced are contained in a precious-metal spinning jet, which may contain as many as 20,000 such holes, often only 0.002 in. diam., with a permitted tolerance of only 0.00008 in. The spinning jets must be strong enough to resist deformation, as well as being resistant to acid and erosive wear. The hole shapes must be extremely accurate, and no burring can be tolerated, as this will cause the fibres to break off short. For this purpose, 10% rhodium-platinum and 30% platinum-gold have been found

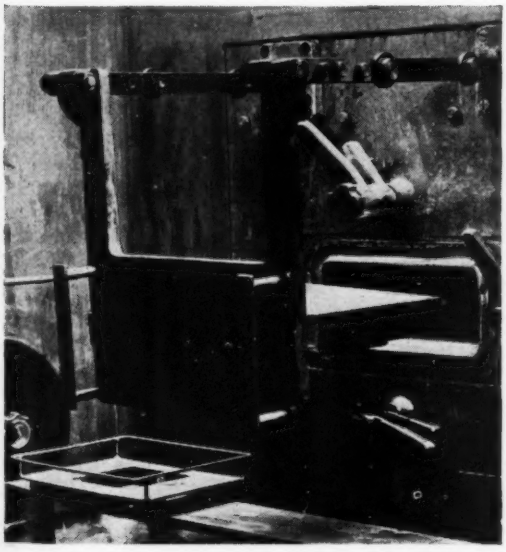


Fig. 6. One of the platinum-lined electric furnaces in the plutonium plant of the Atomic Energy Authority at Windscale

to be ideal materials for this purpose. The gold alloy is usually preferred as it is age-hardening, and hence can be worked in a very soft condition before ageing (Fig. 7).

The high position of platinum in the electromotive force series and its consequent freedom from anodic attack enable it to be used as an anode material under a wide range of conditions.

Platinum-sheathed copper or silver anodes are employed in numerous electrochemical processes and have been developed for the cathodic protection of ships and chemical plant. Typical processes include the manufacture of perborates, perchlorates and persulphates. Fig. 8 shows a pair of platinum electrodes designed to provide adequate current-carrying capacity with the largest possible effective area of platinum per unit weight.

Platinum-faced titanium anodes are a recent development and may be used in a variety of plating and electrochemical processes.

In equipment working at high pressures the long-established safety valve is often supplemented by bursting discs, designed to collapse at a particular pressure. They tend to be better than valves in that they are very quick in response, thus being capable of dealing with explosive conditions, and also because they always tend to fail safe (Figs. 10 and 11).

For the majority of applications, base metal discs are adequate, but platinum finds use in extremely corrosive conditions. Platinum discs have been employed in contact with hydrochloric acid vapours and chlorinated hydrocarbons, and under less corrosive conditions where the prevailing temperature is high, such as in superheated water systems.

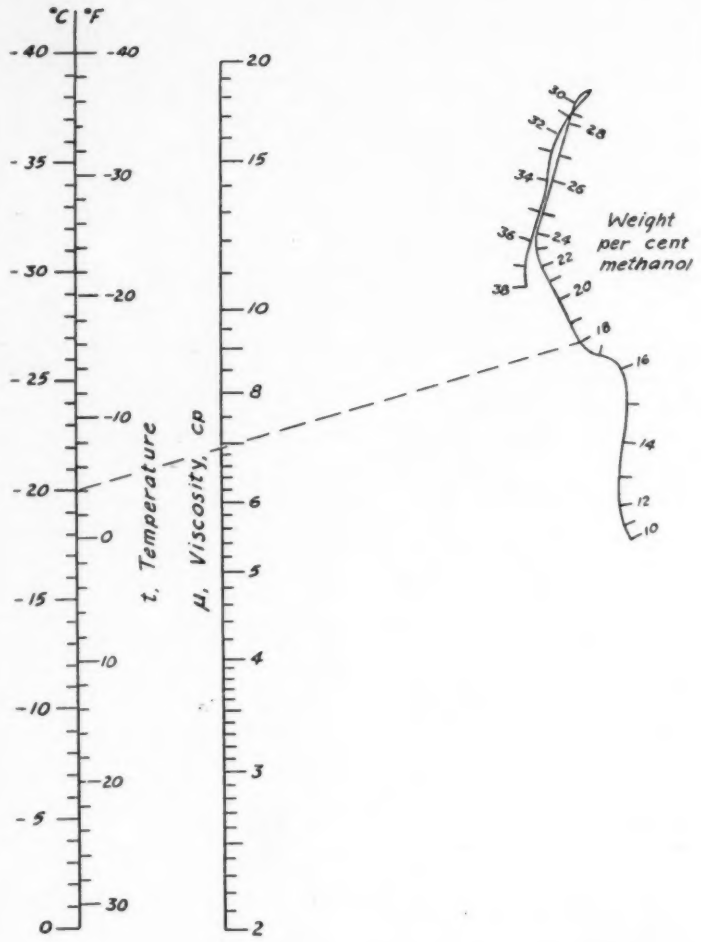
The chief advantage of platinum is its resistance to chemical attack, particularly at elevated temperatures under oxidising conditions. It is easily fabricated, and can be welded by simple fusion so that large and complex pieces of equipment are readily produced. The disadvantage of high initial cost is offset by the high recovery value and the long, trouble-free service.

The material of construction for chemical plant which will be discussed in next month's issue of CHEMICAL & PROCESS ENGINEERING will be

TITANIUM

Viscosities of Aqueous Methanol Solutions

By D. S. Davis*



Well-known data[1] on the viscosities of aqueous methanol solutions can be correlated by means of the equation

$$\log (\mu - 0.003\mu^{2.2}) = a + bt$$

where μ = viscosity (cp.), t = temperature (°C. or °F.) and a and b depend upon the concentration of the methanol.

The accompanying line co-ordinate chart, based on this expression and constructed in accordance with standard methods,[2, 3] enables rapid and accurate estimation of viscosity when the temperature and concentration of the solution are known. The broken index line on the chart shows that the viscosity of an aqueous solution that contains 18% by weight of methanol is 6.9 cp. at -20°C. (-4°F.).

REFERENCES

[1] J. H. Perry, 'Chemical Engineers' Handbook', 3rd ed., p. 1696. McGraw-Hill, New York, 1950.
[2] D. S. Davis, 'Nomography and Empirical Equations', Chap. 10. Reinhold Publishing Corp., New York, 1955.
[3] D. S. Davis (ed.), 'Chemical Processing Nomographs', Unit 1. Chemical Publishing Co. Inc., New York, 1960.

*Professor, Department of Pulp and Paper Technology, University of Alabama.

What's New

in Plant • Equipment • Materials • Processes

CPE reference numbers are appended to all items appearing in these pages to make it easy for readers to obtain quickly, and free of charge, full details of any equipment, machinery, materials, processes, etc., in which they are interested. Simply fill in the top postcard attached, giving the appropriate reference number(s), and post it.

Solenoid valve

To be used in flow systems as an on/off control where the maximum flow rate is 525 ml./min. at 60-cm. head of water, the *Grundy* solenoid valve offered by Griffin & George Ltd. is a cylindrical glass valve with a metal-cored glass plunger actuated by a concentric solenoid from a mains control unit.

The valve has an overall length of 110 mm. and is cylindrical, being 70 mm. long by 16 mm. in diameter, with rifled extensions to accommodate 5-mm.-diam. tubing. The glass valve is mounted through the solenoid which is housed in a metal casting with an integral bosshead to accommodate rods of up to ½ in. in diameter. **CPE 1611**

Distillation apparatus

To be shown at the Physical Society Exhibition by A. Gallenkamp & Co. Ltd. is an automatic standard distillation apparatus for routine distillation tests.

The apparatus, originally developed by Shell, has now been expanded and includes a refrigerator unit which is used to cool the condenser tank of the apparatus for the distillation of materials having highly volatile fractions. The record and collection section of the apparatus is also provided with a supply of cooled air.

The apparatus automatically records the correction temperature, the initial boiling point and the time taken to reach it, the vapour temperature against volume recovery curve, the time taken from the initial boiling point to final heat adjustment, the final boiling point and the time taken to attain it and finally the total recovery. During the distillation the recovery rate is automatically maintained within the limits permitted by specification. **CPE 1613**

The automatic shot-blasting cabinet at West-Loyne Ltd. factory where the service of coating heavy equipment is carried out. The cabinet will accommodate work up to 30 ft. x 12 ft. x 12 ft.

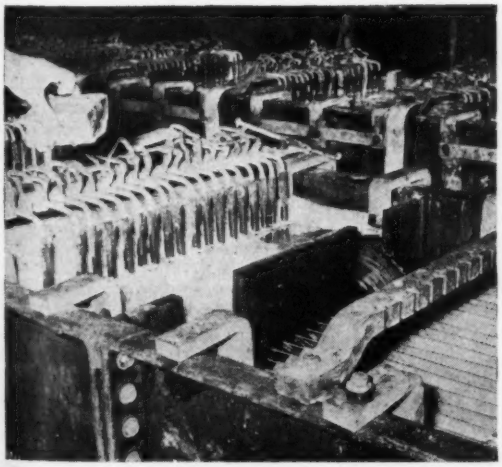
Industrial service

An industrial service—the application of a comprehensive range of anti-corrosion and protective coatings to heavy equipment up to 5 tons in weight, under factory conditions—has been established in Manchester.

The service is based on specialised plant recently installed by West's-Loyne Ltd. The plant includes one of the largest fully-automatic shot-blasting cabinets installed in Britain for this kind of work and a large gas-fired oven for the sintering and stoving of coatings, or the heat treatment of metals. The installation has preparation and coating equipment and the necessary cranes for the moving of large items while under treatment.

The service offered includes technical advice in addition to surface preparation and application and curing of coatings.

Among coatings applied are epoxy resins, phenolics, synthetic rubber,



TREATED PLYWOOD

A chemically-treated plywood, Permaply, *made by Venesta Plywood Ltd., is being used by Rylands Bros. to form baffle boards in galvanising cells. The* 1*-in.-thick plywood (visible in the middle of the picture) has proved capable of withstanding the hot sulphuric acid solution in the cells for at least six months without serious deterioration.* **CPE 1612**

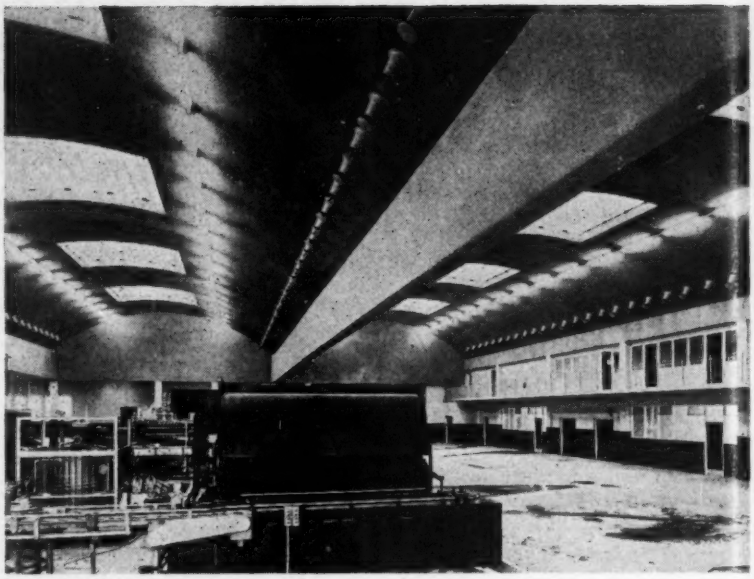
PTFE, PTFCE, silicones, metal spraying and flame spraying.

The gas-fired oven is designed for sintering PTFE and PTFCE and for stoving high-bake epoxy, phenolic and silicone coatings. A temperature of 450°C. can be attained when needed for heat treatment of metal if required before PTFE coating. Provision is also made for curing coatings by hot air and infra-red heaters.

Other facilities available include the shot-blasting of very large vessels in the open with mineral grit and, if required, work can be prepared by flame cleaning and power wire brushing.

Both powder and wire metal spray guns are used for flame spraying zinc, aluminium and stainless steel as well as for the synthetic coatings.

Pipes and ducting can be internally coated by spray or flow coating. Other types of application are by spray, brush and trowel. **CPE 1614**



The brewery where sprayed vermiculite/cement rendering has been used to prevent condensation on the roof

Condensation problem

Sprayed vermiculite/cement rendering by Pyrok Ltd. has been used to overcome condensation problems in the new bottling hall of the Newcastle Breweries Ltd.

It was essential to have a clear floor area in the bottling hall itself of 150 ft. × 200 ft., to give freedom in planning and the layout of the plant. To achieve this, a concrete shell roof was adopted consisting of four bays each 150 ft. × 50 ft. span.

To avoid condensation the following points were considered: Adequate ventilation and extraction of air, with a warm current of air over the ceiling area; insulation of the roof, externally; and treatment of the underside of the vaulted roof. For the latter, *Pyrok* was selected.

Vermiculite renderings are known for their properties of adhesion, fire resistance, thermal insulation and prevention of condensation and subsequent corrosion or damage.

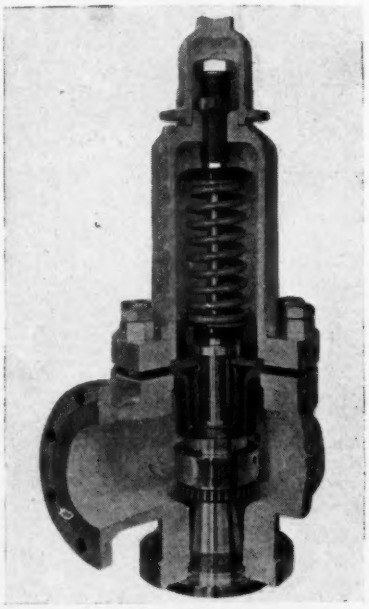
To avoid fungicidal growths, a special anti-fungicidal solution was incorporated in the mix, and after 18 months this has proved to be satisfactory. It is claimed that, under extreme conditions of humidity, no condensation has resulted. **CPE 1615**

Quick-release strainers

A new range of *Fram* industrial strainers offered by Simmonds Aerocessories Ltd. includes models fitted with both ' quick-release ' and bolted covers. They are designed for use in general industrial processes where a high solids content in a liquid or gaseous stream may occur.

Quick-release cover strainers are said to be suitable for those industries which need to impose close limitation on the possible introduction of extraneous matter into the stream.

Two versions of the strainer are available. In one, the flow is so arranged that the sludge, strained out of the gas or liquid is deposited in the strainer basket, which is then removed and cleaned. In the other, an out-to-in flow is established, by which contaminants are trapped in a sump at the base of the strainer, where they are drained by means of a cock. Both types of strainer have a high-grade cast-iron body. **CPE 1616**



Safety relief valve

Relief valve

A safety relief valve which is unaffected by variations in superimposed back pressures in the discharge system is offered by Crosby Valve & Engineering Co. Ltd. The design combines the features of the two existing methods of balancing against back pressures—bellows seal and piston balance.

With the balancing bellows seal, back-pressure effects are eliminated and no atmospheric vent is necessary. In the event of the bellows being ruptured the balancing is taken care of by the piston immediately above the bellows, ensuring that the valve still remains unaffected by back pressures. **CPE 1617**

Density gauge

A gauge intended to indicate density changes in any liquids, solids and slurries in a wide range of industrial processes is offered by Saunders Roe & Nuclear Enterprises Ltd.

Basically, the system consists of a caesium-137 source ' looking through ' the inspection volume at a plastic

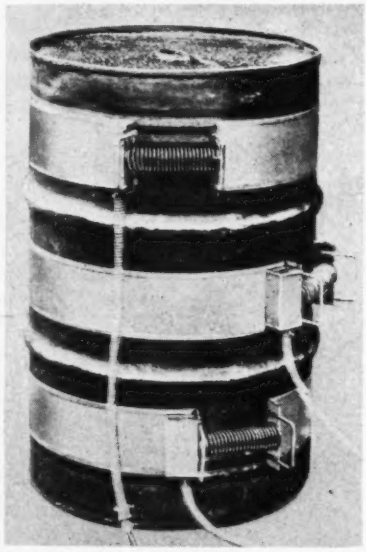
phosphor mounted on a photomultiplier. The amount of radiation which reaches the detector is dependent on the density of the material in the process.

'Stopping power' of this system is said to be of the order of 30 times greater than that of an ionisation chamber and hence with similar sources the sensitivity is much better.

The photomultiplier is arranged to give a signal which is monitored by a Honeywell Brown recorder. This is arranged to have a suppressed zero, so that the required variations in density are covered by the recorder scale. **CPE 1618**

Drum heater

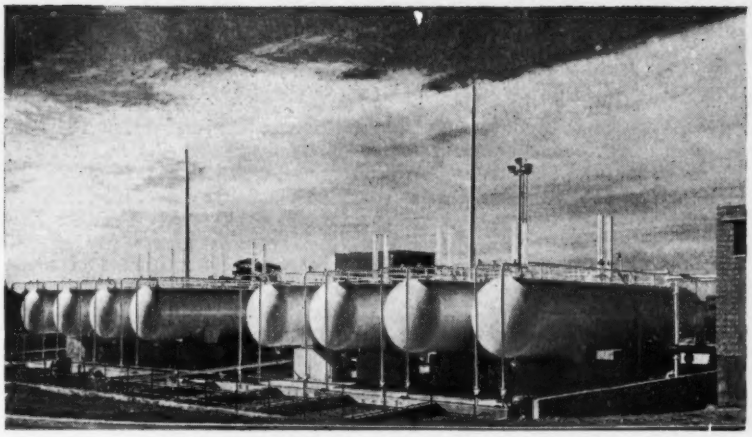
A drum heater unit is offered by Electrothermal Engineering Ltd. to provide speedy application of heat to drums containing viscous or solidified materials such as greases, wax, tar, asphalt, bitumen, paint and gelatine. They can also be used for drying after washing.



Drum heater unit for viscous or solidified materials

By using single or multiple heaters it is possible to apply heat to any, or all, sections of the drum which eliminates wasted heat when only a portion of the drum requires heating. The amount of heat applied can be regulated by the use of single or multiple control units.

The heaters weigh about 9 lb. and thus can be taken to the drums, so avoiding manhandling of the drums. They are made in stainless steel. **CPE 1619**



The eight storage vessels at the butane/air plant at Hereford

Butane/air plant

A butane/air plant has recently been commissioned by W. C. Holmes & Co. Ltd. at the Hereford works of Henry Wiggin & Co. Ltd.

The plant has been designed to store 500 tons of liquid butane (the equivalent of some 240,000 therms) and to supply the total gas requirements of a modern factory of 50 acres.

In operation, butane vapour is mixed with air. This serves a dual purpose, it reduces the high heat content of the vapour to a usable value and it also reduces its dewpoint. This reduction of dewpoint eliminates the possibility of the vapour separating from the air and condensing in the distribution pipelines. The butane/air mixture may be used in place of coal gas providing suitable burner adjustments are made where necessary.

There are eight storage vessels, each of which is 10 ft. diam. × 56 ft. 6 in. long. When filled to 86% of their total capacity the required total of 500 tons of liquid butane is reached. The remaining 14% of capacity forms the vapour space and allows for expansion of the liquid.

Each vessel is fitted with water spray manifolds which, when necessary, can supply an adequate covering of water. This acts as a protection from either an abnormally high ambient temperature or radiated heat. As water supplies were limited on site, a small reservoir has been incorporated in the plant, the return water being drained from underneath the vessels and recirculated by means of submersible water pumps. **CPE 1620**

Silica analyser

An automatic instrument that continuously analyses the silica content of boiler feed water is offered by Electronic Instruments Ltd. It is said to eliminate the tedium and uncertainty of manual determinations and thereby ensure that the boiler feed water is monitored sufficiently frequently and rapidly to enable steps to be made immediately to reduce the silica content.

The instrument is essentially a colorimeter in which the colour of a solution to which reagents have been added is a measure of the concentration of silica in that solution.

A measured sample of water is taken automatically, a fixed volume of molybdate solution is added and then the reducing agent. The stirred mixture eventually develops a blue colour and is then delivered to an optical comparator and the blue shade photo-electrically compared with a perspex blank or, if the water is discoloured with the original water.

The instrument is available in three ranges: 0 to 0.2 part of silica per million of water, 0 to 2.5 p.p.m. and 0 to 30 p.p.m.

The complete cycle of operations takes 12 min. Stirring and reducing process in the mixing vessel occupies 9 min. The additions of the sample and the reagent to the reaction vessel together occupy the other 3 min. The differential output of the photocells in the colorimeter feeds a transistor amplifier, which gives an output of 1 mA into a resistance of 1,500 ohms for full-scale deflection. The output drives a suitable recorder. The whole sequence, being entirely automatic, is controlled by a mechanical programme timer. **CPE 1621**

New Books

Tables for Petroleum Gas/Oxygen Flames: Combustion Products and Thermodynamic Properties. By I. I. Berenblut and Anne B. Downes. Oxford University Press, London, 1960. Pp. 107. 30s.

There can be few computations more tedious than that of the flame temperature for a system in which a variety of dissociation reactions occur. Therefore, one warmly welcomes publications, such as those of the United States Bureau of Mines and the present volume, which offer tabulated results of such calculations for certain fuels and mixtures. In the present instance the fuels concerned are propane, propylene, butane and butylene and equimolecular mixtures of propane and butane, the C_3s and the C_4s in turn. The calculations have been carried out with the aid of an electronic digital computer.

Adiabatic flame temperatures corresponding to the combustion of series of fuel-rich fuel-oxygen mixtures at atmospheric pressure and an initial temperature of 25°C. are plotted and tabulated. The dissociation of carbon dioxide, water vapour, hydrogen and oxygen are taken into account in computing flame temperatures and flame gas compositions (which are also tabulated), but carbon formation is ignored as are, of course, heat losses from the flame. Thermodynamic properties of the flame gases, including specific enthalpy, specific entropy, specific heat at constant pressure, adiabatic index, molecular weight and density, are also tabulated and further tables show equilibrium composition and thermodynamic properties of the flame products at a series of temperatures below the maximum attainable.

A short introduction outlines the methods of calculation employed and gives necessary information about the tables. A minor criticism is that certain essential information, for example that all oxygen/fuel ratios are by volume, is given only in the introduction. The use of the tables would be facilitated and possible misunderstandings avoided if all headings were quite explicit as to conditions, units and the meaning of symbols.

It would be ungracious, however, to conclude without an expression of appreciation of the great amount of work that has gone into the compilation of this small volume. There is no doubt that it will be of considerable value to those who are concerned with technical aspects of the utilisation of the liquefied petroleum gases. It is to be hoped that the authors and others will be disposed to compile similar data for other fuel systems and so save many the tedium of computations for which they do not have the most suitable facilities.

J. H. BURGOYNE

Using Centrifugal Pumps. By E. Allen. Oxford University Press, 1960. Pp. 246. 30s. net.

There is no doubt that the author has taken great pains to ensure that the practical aspect of centrifugal pump operation and maintenance is likely to prove very useful to plant engineers.

In Chapter 1 it would have been a little more informative if, for example, the sectional diagrams could have been broken down to show more clearly the details of bearings, shaft location collars, etc., and perhaps some reference could have been made to possible causes of mechanical failure. Such information would be invaluable to pumping-plant operators and maintenance engineers.

Chapters 2 to 12 deal mainly, in a very detailed manner, with the relationship between pump and system characteristics. It should assist anyone who is not too familiar with the technical aspects of pumping plants to understand which type of pump should be used for a particular application and to indicate an approach to design features. On page 60 to 62 relating to mine pumps, the point in question is that the pressure balance at the middle section of pump A would be critical to the low level and perhaps a more usual way would be to use two pumps at low level, both operating in parallel.

Chapters 13 and 14 deal with fire-fighting duties and vertical pumps. These duties contain a certain amount of useful data such as nozzle discharge, reactions, etc., but do not include anything of particular interest beyond illustrating the manner in which these pumps are arranged to suit operating conditions.

Cavitation, as described in Chapter 15, can, of course, occur with any centrifugal pump. In the opinion of this reviewer this phenomenon rarely occurs for normal cold water duties, because suction lifts are usually operated at something well inside the manufacturers' recommended maximum lift. The author has described cavitation symptoms correctly but, beyond this, the matter is perhaps no more than of academic interest unless one considers pumps fed from pressure vessels, condensers, etc., where the suction head may be variable and conditions of vaporisation occur in the eye of the impeller.

One of the most useful sections of this book is Chapter 20—'Pot-Pourri'. The simplified form in which technical information on this subject is given should help any engineer without much technical background to understand it. Indeed, this is probably one of the most informative chapters in the whole book.

Finally, having regard to the fact that hydraulics applied to centrifugal pumps is not, by any means, an exact science and such pumps often perform in mysterious ways, the author should be heartily complimented on the care he has taken in preparing this book for publication.

A. FLINDLE

Glass: Its Industrial Applications. By C. J. Phillips. Chapman & Hall, 1960. 56s. net.

This is the third contribution by Mr. Phillips to the literature on glass and, like its predecessors, it is written in an interesting, readable style and well illustrated. It is, of course, not possible to give in a book of some 250 pages an exhaustive account of all the applications of glass in modern industry but useful information is easily available and the references included with each chapter should enable the more energetic reader to develop his interests.

The first six chapters give a brief account of the history of glass, its melting and manufacture, and the physical and chemical properties of various types. (A note of caution here: Mr. Phillips takes his data from the American manufacturers and the properties of the British counterparts in some cases will be slightly different to those quoted.) He then deals, perhaps too briefly, with the application of glasses in building construction, packaging, and laboratory ware; more extensive chapters follow on the use of glass in the chemical industry, electronics, illumination, optics, special glasses, including glass ceramics, and glass-fibres.

In his preface the author states: 'It

(the book) should be of value to men and women in industry—engineers, scientists, production people, purchasing agents—who are involved in the design, specification, testing, fabrication purchase or sale of glass products'. Some readers will consider this an overstatement of its worth.

C. THORNE

Rocket Propellant Handbook. By Boris Kit and Douglas S. Evered. Macmillan Co., New York, 1960. Pp. 354. $12.50.

An outline of the fundamentals of rocket propellants is given in the first section of this book. This is broken down into general principles and classification, liquid propellants and solid propellants. The subject is discussed clearly, the important characteristics being outlined.

The bulk of the text follows this introduction to the subject; it deals individually with the chemicals used in rockets, and for this purpose the chemicals are divided into inorganic propellants and organic propellants. Each material is discussed under six headings:

(1) Introduction
(2) Physical and chemical properties
(3) Production availability and cost
(4) Storage and handling
(5) Toxicity
(6) Performance as a propellant

The descriptions of the chemicals are not entirely balanced, as some aspects of certain materials are dealt with in more detail than others. It is understandable that information may not be available on some chemicals, but surely sufficient information has been published on the physical properties of water to warrant the inclusion of more values than the seven quoted in Table 17-1. The storage and handling of some substances is described in great detail, *e.g.* hydrazine and hydrogen peroxide. Comprehensive tables of compatability with materials of construction are given for these chemicals. On the other hand, the information given on ammonia does not include any mention of materials of construction, and there is a vague statement on page 41 to the effect that aluminium is resistant to some mineral acids. It is difficult to see why cost has been included in heading No. 3 as actual costs are given in only a few instances.

The last section of the book deals with pressurising gases, and it consists mainly of tables of the physical properties of air, helium and nitrogen. Appendices cover definitions, physical properties of chemicals and conversion factors.

There are several misprints in the text; where these occur the meaning will be clear to chemists, but what does one make of the statement on page 196, 'Ozone is toxic even in low concentrations', followed on page 197 by 'neither ozone nor its products of combustion are toxic or corrosive'? When the user of a handbook of this type finds misprints and errors in the text, he naturally wonders if errors and misprints have crept into the tables of physical constants where they may not be so obvious.

A considerable amount of information has been assembled in this handbook, and it is pleasing to find that physical constants are given in English and metric units. Many references to other sources of information are given, and the book should be of value to workers in the field of rocket propulsion.

E. W. JACKSON

Radioactive Tracers in Chemistry and Industry. By P. Daudel. Charles Griffin Co., London, 1960. Pp. x + 210. 36s. net.

This English version of Mme. Daudel's monograph 'La radioactivité au service de la chimie et de l'industrie' first published in 1955, amounts to a new edition as it has been revised by the authoress and new material has been added.

The book is of an introductory nature, although it is assumed that the reader has some familiarity with the fundamental phenomena of radioactivity. General principles of the use of radiotracers and the preparation of labelled molecules are briefly discussed first. Successive chapters deal with the use of tracers in the study of chemical reaction mechanisms, exchange reactions, and applications in analytical chemistry. Uses of radiotracers in industry are considered in the final chapter.

The volume is of convenient pocket-size and contains numerous references.

D. F. C. MORRIS

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are retail booksellers and will be pleased to supply any books reviewed in CHEMICAL & PROCESS ENGINEERING. Immediate attention will be given to any requirements you may have for these or other works.

Chemistry and Chemical Engineering. By A. J. Bune. The Sunday Times, 1960. Pp. 104. 3s. 6d. net.

The *Sunday Times* has undertaken the very worthy task of compiling career books for young people about to leave school. In previous years such booklets were prepared by the Ministry of Labour, and one remembers that they withheld more information than they revealed. A young boy or girl at the age of sixteen who is about to decide which career (if any) to embark upon, wants to find out not only the career prospects of a certain profession but also the financial prospect which this profession has to offer.

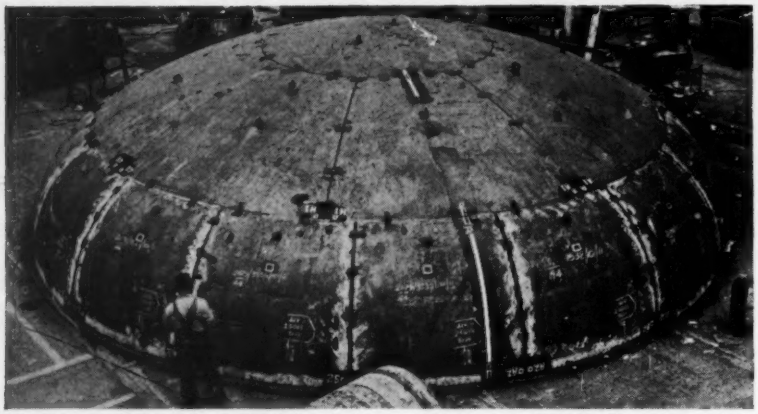
The field covered by chemistry and chemical engineering is so wide that many generalities have been made in this book which are quite inaccurate upon closer acquaintance. The earlier chapters define the scope of chemistry ranging all the way from the origin of synthetic dyestuffs to the discovery of penicillin and plastics, briefly touching upon the less-colourful aspects of routine heavy chemical manufacture. A few pages describe the training which a student must undergo in order to qualify as a chemist or a chemical engineer: either by first graduating at a university and subsequently applying for membership of the Royal Institute of Chemistry or the Institution of Chemical Engineers, or by only taking the examinations of these professional bodies.

A whole chapter is devoted to research in chemistry, describing some activities of the National Chemical Laboratory and various D.S.I.R. establishments; pointing out to the romantic young soul how great inventions like manufacture of polyethylene had humble origins firmly set in the research laboratory. Various branches of the chemical and nuclear industry such as petroleum, fine chemicals, plastics and fibres, food and nuclear science are described in subsequent chapters.

Unfortunately, information regarding salary prospects in these industries are limited to the Scientific Civil Service (which only employs a minority of chemists and engineers)—it would have been most helpful if some kind of salary scale, similar to that recently devised by the A.B.C.M., could have been included. The main criticism that must be levelled is that altogether too much information has been presented in too concentrated a form.

I.L.H.

Orders and Contracts



The photograph shows the top head of a 35-ft. 8-in. inside diam. × 45 ft. long regenerator which Ashmore, Benson, Pease and Co. Ltd. are making for Brefcon Ltd. on behalf of Petroleo Brasileiro S.A. for their Duque de Caxias refinery

Elimination of iron oxide fumes

A contract to supply a complete gas cleaning plant has been awarded to Chemical Construction (G.B.) Ltd. by Gutehoffnungshutte (G.H.H.) to be used in conjunction with the oxygen steel-making rotor furnace G.H.H. are supplying to Richard Thomas & Baldwins at their Redbourn works in Scunthorpe. The Chemico plant will be a venturi scrubber for the elimination of iron oxide fumes.

The gas cleaning plant will handle 106,000 cu.ft./min. of saturated gas and includes a filtration plant for the removal of solids from the scrubbing water.

It is expected the installation will be in operation early this year.

Drying plant

Buell Ltd. obtained an order from the Lancashire Steel Manufacturing Co. Ltd. for the supply of drying plant complete with high-efficiency dust collectors and other ancillary equipment. The plant will handle 225 tons/hr. of wet Northants ore, containing an average moisture not exceeding 18%, to be dried to a final moisture content not exceeding 12%. The company's engineers and outside erection staff are erecting this plant completely on their clients' prepared foundations. The total value of the contract exceeds £200,000.

Stainless-steel tubing

Two orders for welded stainless-steel tubing, totalling more than £120,000, have been obtained by Rollo-Hardy & Co. Ltd., a member company of the Compoflex group. The orders are from Czechoslovakia and Finland, and cover tubing of from 25 to 57 mm. o.d., for use in chemical plants. The machinery on which the tubing for these orders is being made was designed and built by Tube Making Machines Ltd., another company in the group.

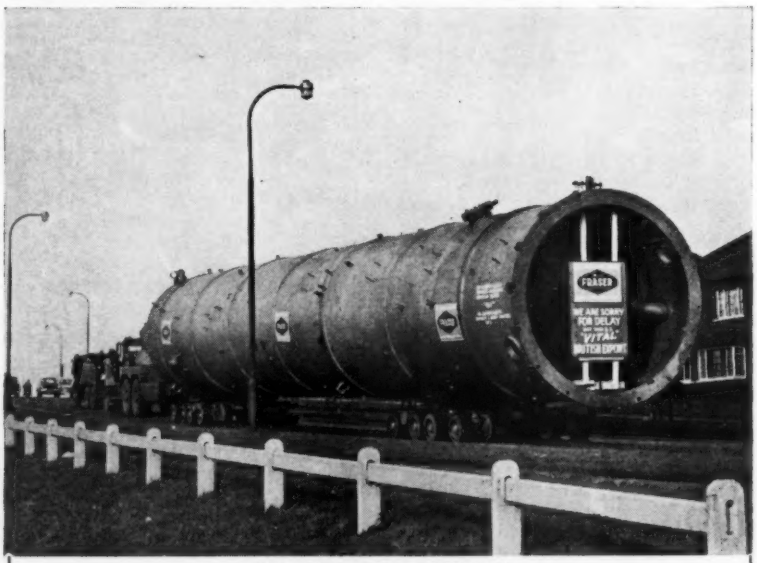
Effluent treatment

William Boby & Co. Ltd. have been awarded a £25,000 contract by the English Electric Co. Ltd. for effluent treatment plant at Hinckley Point nuclear power station.

Contracts for polystyrene plant

The award of the final contracts for completion of a polystyrene-production plant in Greece has been announced by Dow Chemical International Ltd., S.A.

The new manufacturing facility for Dow Hellenic Chemical Industry Ltd., near Athens, will be built by Foster Wheeler Italiana. Plastics technical service facilities are also included in the construction plans for the plant; completion is scheduled for late November, 1961.



FOR MEXICAN REFINERY

Part of an export order worth £100,000 built by W. J. Fraser & Co. Ltd., at their Barnsley Works, this 90-ft.-long refinery column is 13 ft. diam. and weighs over 70 tons. It is for the new Petroleos Mexicanos refinery at Minatitlan, Mexico, and is to be shipped from Liverpool as deck cargo on the m.v. Adventurer.

Electrolytic chlorine production

The general chemicals division of I.C.I. Ltd. has placed an order with the heavy plant division of A.E.I. Ltd. for germanium rectifiers with a capacity of 32.4 MW at 270 V, for the electrolytic production of chlorine. This is believed to be the largest order for semiconductor rectifiers ever placed by the chemical industry in the U.K.

CPE World News

NEW ZEALAND

Distillery

The foundation stone of a new distillery of the New Zealand Distillery Co. in Epsom for the production of gin was laid recently.

Half the capital has been provided by British companies and half by 96 wholesale merchant firms throughout New Zealand. The distillery, which alone will cost £400,000 is only the first stage. It is to be the foundation of a larger industry to compete with imported goods.

The rectifying companies in New Zealand would be under the control of the various U.K. distilling interests. In this way it is expected to assure an article equal in quality to imported brands. It is hoped that the excise duty allowance will result in a reduced price.

INDIA

Control equipment

Elliott-Automation Ltd. is supplying the complete instrumentation and control equipment for the oil refinery being supplied for Assam by the Roumanian State Trading Agency, Technoimport. The 64-ft.-long main control panel has been shipped to India. It contains instruments manufactured by Elliott Bros. (London) Ltd., Panellit Ltd., James Gordon Ltd., the Swartwout Co., Bristol's Instrument Co. and Electroflo Meters, all members of the Elliott-Automation Group. Fisher Governor Farris and Continental valves and control equipment are being used exclusively throughout the refinery and Hallikainen quality control instruments are also being supplied by the Group.

NETHERLANDS

Polypropylene for plastics

Bataafse Petroleum Maatschappij N.V. and Montecatini, Societa Generale per l'Industria Mineraria e Chemica of Milan, have agreed to form a joint company in the Netherlands.

The purpose of this new company will be to build and operate at Rotterdam, in conjunction with the works of Shell Nederland Raffinaderij N.V., a factory to manufacture, in the first phase and on a large scale, polypropylene for plastics.

SPAIN

New company after legislation

Monsanto Overseas Ltd., jointly with Aiscondel S.A. of Barcelona has formed a new company, Monsanto Iberica S.A.

This is one of the first companies to be created under a recently enacted Spanish law which governs foreign investments and permits equity of up to 50% by foreign companies. Previously foreign equities were generally limited to a maximum of 25%.

The venture is already in production, having acquired an Aiscondel subsidiary plant near Barcelona which produces plasticisers, stabilisers and lauryl peroxide for the plastics processing industry.

Construction of a plant will begin immediately at Monzon to manufacture calcium carbide, acetylene and acetylene derivatives. The plant is expected to commence initial operation late this year.

MOROCCO

Group of chemical plants

A government organisation, Maroc Chimie, in conjunction with foreign capital, is to build a group of chemical plants in the region of Safi. Output will include triple superphosphates (200,000 tons p.a.), sulphuric acid (400,000 tons) and phosphoric acid (180,000 tons). An associated plant, to be built by Royal-Dutch-Shell and the Bureau d'Etudes et de Participations Industrielles, will produce over 100,000 tons of ammonium phosphate. All these projects are to be started this year and completed by 1963.

Sixty-four feet long control panel for oil refinery in India

IMPORTANT ANNOUNCEMENT

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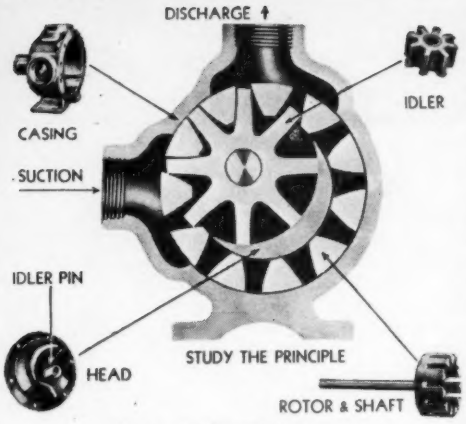
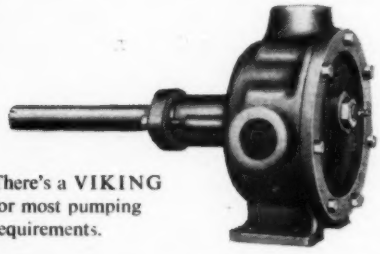
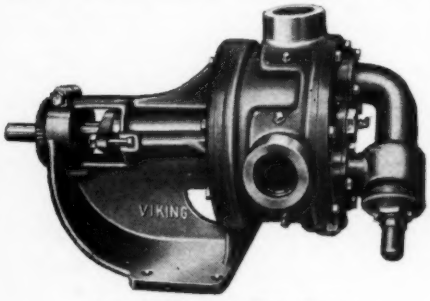


The heart of the Viking pump



There's a VIKING for most pumping requirements.



A VIKING Heavy Duty Pump

VIKING PUMPS

range in capacity from 2/3 to 1050 gallons per minute.

More than 750 standard types are available and special models can be supplied to individual requirements.

Personal Paragraphs

★ **Mr. G. H. Lowthian,** M.B.E., has been elected chairman of the Industrial Training Council. He succeeds **Lord McCorquodale** who has been the chairman since the council was set up in July 1958. Mr. Lowthian is the general secretary of the Amalgamated Union of Building Trade Workers and a member of the General Council of the T.U.C.

★ **Professor L. P. Hammett** of Columbia University has won the American Chemical Society's 1961 Priestly Medal, the highest honour in American chemistry. His research has been mainly on the speed of chemical processes and the arrangement of atoms within molecules.

★ **Mr. S. G. Harmer,** works manager for the past 11 years of Whiffen & Sons Ltd., has been appointed a director of the company.

★ **Commander E. G. Sutton** has been appointed works director of Sir W. H. Bailey & Co. Ltd. A former chairman of the Admiralty Remote Power Control Panel, he was manager and director of a company in the John Thompson group concerned with the charge face equipment for Berkeley Nuclear Power Station.

★ **Mr. A. Hilliard,** technical adviser to the Société Carbon-Lorraine, has been adjudicated the second research award in the Waverley gold medal competition of the Royal Society of Arts for his paper 'The *Polybloc* system of Construction for Anisotropic Materials'.

★ **Mr. William Collinson,** chairman of William Blythe & Co. Ltd., completed 75 years with the company recently. He joined the company at the age of 13 as an office boy and was appointed managing director in 1919.

★ **Dr. J. B. Adams,** Director-General of C.E.R.N., has been awarded the Duddell medal by the Council of the Institute of Physics and the Physical Society for his leadership of the C.E.R.N. team.

★ **Mr. Clifford J. Smith** has been appointed as manager of the filter division of Eimco (G.B.) Ltd. in succession to **Charles E. Silverblatt.**

★ **Mr. Alan S. Gill** has retired from the board of George Cohen Sons & Co. Ltd. on reaching the age of 65. He will now practice as an industrial consultant.

★ **Mr. O. Secher** has been appointed vice-chairman of Marchon Products and Solway Chemicals Ltd. He has been with Marchon Products Ltd. since its inception in 1939. Both companies are members of the Albright and Wilson Group. **Prof. G. H. J. Daysh** has been appointed to the board of Solway Chemicals Ltd. A Sub-Rector of King's College, Newcastle, he holds the Chair of Geography in the University of Durham and is a recognised authority on the topography and economics of Cumberland. He was associated with the late Lord Adams in the rehabilitation of industrial West Cumberland and took a special interest in the development of Solway Chemicals' anhydrite mine at Whitehaven.

★ **Commander A. T. Bond** has been appointed director of sales for P. Leiner & Sons (Wales) Ltd. He joined the company 12 years ago as assistant to the general manager at the Treforest factory.

★ **Mr. John Fletcher** has been appointed manager of the general chemicals division of Cyanamid of Great Britain Ltd. He was previously connected with paint and plastics industries and will now be responsible for the bulk sales of Cyanamid's chemical products in the U.K. which will include the sales direction for melamine crystal production from the company's new Gosport plant.

★ **Mr. E. H. S. van Someren** has joined the British Welding Research Association as a principal scientific officer and is to work on fundamental studies on the physics of the welding arc by optical observations. Since 1958 he has been in the Research Department of Murex Welding Processes Ltd.

★ **Mr. Rupert Withers** has decided, while continuing his full-time executive capacity as deputy chairman of the board of Ilford Ltd., to relinquish his appointment as joint managing director. **Mr. James Mitchell,** the present sales director, has been appointed to succeed him as joint managing director.

★ **Mr. J. R. Jarratt,** manager of the chemical works of Boots' Beeston factory group, has been awarded the Lampitt Gold Medal of the Society of Chemical Industry.

G. Gordon Jackson

O. Secher

★ **Mr. G. Gordon Jackson** has been appointed to the newly-created position of chairman of the board of Americal Machine & Foundry Ltd. He will continue temporarily in his present position with Mitchell Engineering Ltd. as manager of the engineering division. The two companies are associated in the atomic energy field.

★ **Mr. J. McNicol Bruce** has been appointed as engineering manager of Blaw Knox Chemical Engineering Co. Ltd. For the past 10 years he has been technical director of Q.V.F. Ltd.

Howard Acheson

J. McNicol Bruce

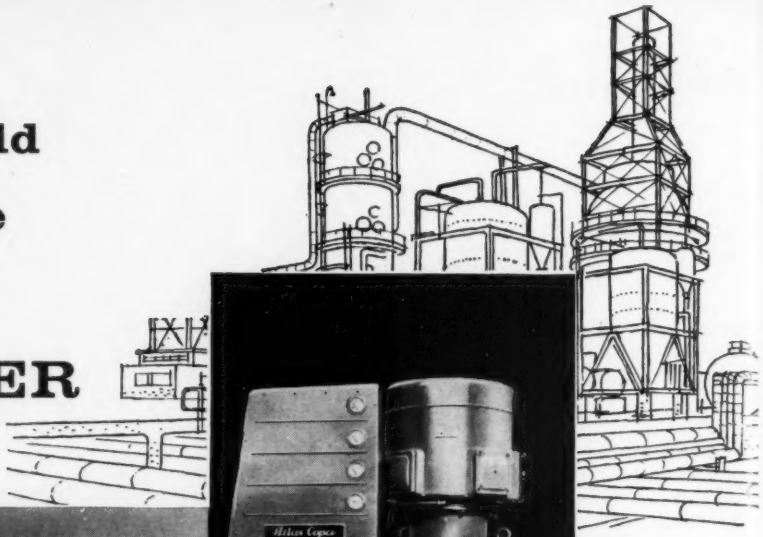
★ **Mr. Howard Acheson** has been appointed general manager of Acheson Dispersed Pigments Co., near Manchester, a division of Acheson Industries (Europe) Ltd. Till this appointment he was production engineering manager of the parent company in Philadelphia.

★ **Mr. Ian MacLeod** has been appointed technical director of Lightnin Mixers Ltd. which was formed recently by Sockdale Engineering Ltd. and Mixing Equipment Co. Inc. of U.S.A. For the last two years he has been technical director of Stockdale Engineering Ltd.

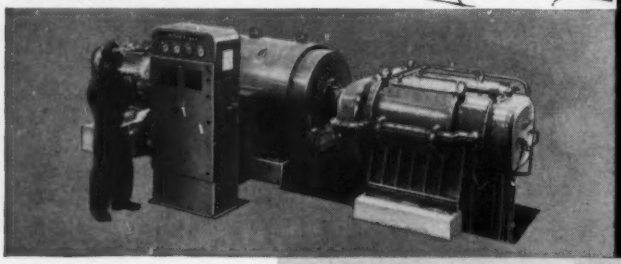
J. R. Jarratt

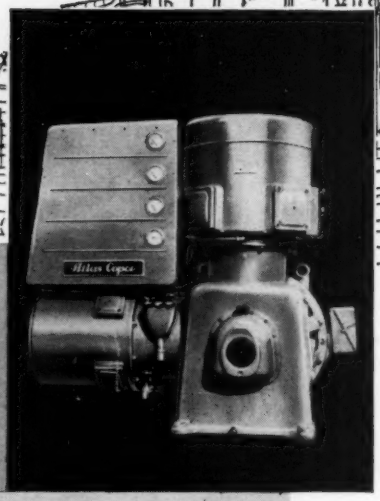
Ian MacLeod

Here's a world of experience in AIR POWER

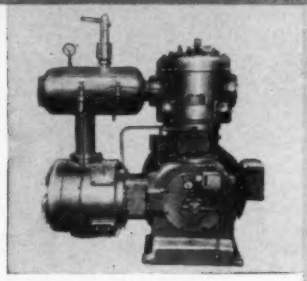


Twin-Air Rotary Screw Compressor

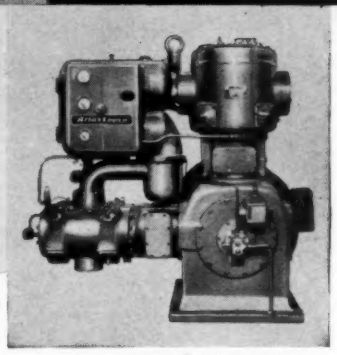




ER6 Compressor



AA-type low pressure Compressor



AR-type high pressure Compressor

...at the disposal of the Chemical Industry

WHEREVER compressed air plays a part in industry, Atlas Copco is a familiar name. No matter what the application — from operating a small spray-painting unit to supplying the large air needs of a complete factory—there are Atlas Copco compressors to give you the best possible combination of performance, reliability and economy.

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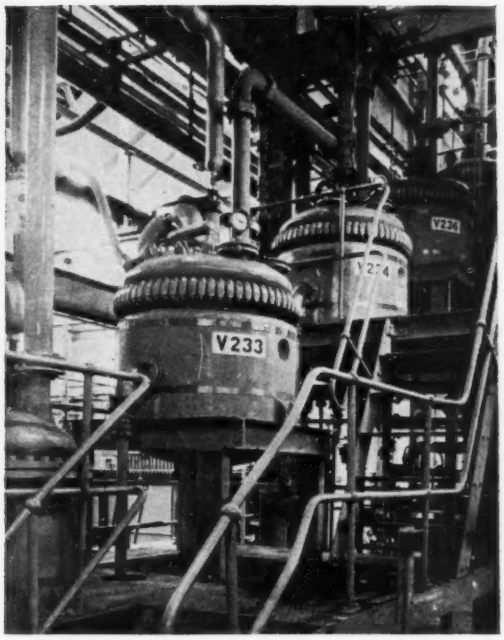
CPE Company News



A reaction cascade at the sodium chlorite plant of Laporte Chemicals Ltd. at Luton

Sodium chlorite plant

Production of sodium chlorite has now started at the Luton plant of Laporte Chemicals Ltd. The *Kesting* process, licensed by Elektrochemische Werke Munchen, is used. In this process a solution of sodium chloride and chlorate is circulated through a battery of electrolytic cells. A portion of the electrolyte is continuously withdrawn and reacted with acid to release chlorine dioxide and chlorine. The chlorine dioxide is purified and combined with caustic soda and hydrogen peroxide to give a solution of sodium chlorite.

This is the first chlorite plant to go into production in Great Britain. The plant is largely constructed of plastic, glass, ceramic, stainless steel and titanium metal. It is housed in the building which was previously used for the production of hydrogen peroxide by the electrolytic method.

Commercial refrigeration

Baker Perkins Ltd. have acquired Alfred Porter & Co. Ltd. and its three affiliated companies. Alfred Porter & Co. Ltd. manufacture industrial and commercial refrigerating and dehumidifying plant for use in the air-conditioning chemical and cold storage industries.

The operations of the company will be integrated with William Douglas Ltd., a member of the Baker Perkins group.

Acid-grade fluorspar

Laporte Industries Ltd. have bought from Head Wrightson & Co. Ltd. the whole of the issued capital of the Cupola Mining & Milling Co. Ltd. for an undisclosed price.

The Cupola Co. is engaged in the treatment of fluorspar and barytes, and Laporte intends to meet the rising demand for acid-grade fluorspar by expanding production at the flotation plant at Stoney Middleton, Derbyshire, which has recently been installed by Head Wrightson & Co. Ltd.

The operations of the Cupola Co. will be integrated with those of Glebe Mines Ltd., another Laporte subsidiary engaged in similar operations in the same area.

A works closes down

The Silvertown factory of I.C.I. Ltd. is to be shut down at the end of March.

The works produces sodium carbonate which the company's alkali division also produces in a large plant at Winnington, Cheshire. With the recent advance of modern synthetic detergents the demand for washing soda had declined to a point where it is more economic to concentrate manufacture at Winnington where there is better access to the necessary raw materials and services.

Silvertown works of Brunner, Mond & Co. was built in 1894 to make washing soda from soda ash bought from Cheshire. A year later a caustic soda plant was erected using raw material from the same source, but just before the first world war caustic soda manufacture was concentrated at Winnington. During the war, at the request of the Government, the disused caustic plant at Silvertown was adapted as an emergency measure for purifying TNT until new specially designed factories could be built.

Methanol manufacture

Grangemouth Dean of Guild Court has approved proposals by British Hydrocarbon Chemicals Ltd. for erection of three plants, cooling tower and offices at Grangemouth at an estimated cost of £816,500. The three plants will manufacture methanol for the synthetic resins industry, butadiene for synthetic rubber manufacturing and ethylenedichloride for the plastics industry. This development continues the build-up of chemical industry activity at Grangemouth where the 15-year-old expansion programme is still being actively operated.

Rubber company's gift

Dunlop Rubber Co. Ltd. have entered into a deed of covenant to pay £10,000 a year for seven years to Birmingham University.

The gift is in answer to an appeal from the University who are planning to raise £1,638,250 for the purposes of building new halls of residence. Birmingham has 460 students in residence out of a total of 4,000.

By 1965, the total number of students should be over 5,000 and the University plan to raise the number of residential places up to 2,000.

Sulphamic acid

A plant to manufacture sulphamic acid (amido sulphonic acid) with a capacity to meet the U.K.'s known requirements is to be built at the Whitehaven factory of Marchon Products Ltd. The manufacture of ammonium sulphamate is also contemplated. Sales of both materials will be in the hands of Albright & Wilson (Mfg.) Ltd. Both companies belong to the Albright & Wilson Group of companies.

Nuclear Notes

Head of C.E.R.N.

The Austro-American scientist Prof. Weisskopf has been appointed as fourth Director-General of the European Organisation for Nuclear Research (C.E.R.N.) and will serve for two years from August 1. He will succeed Dr. J. B. Adams who is to return to the United Kingdom as director of the Culham laboratory for plasma physics research.

Prof. Weisskopf was born in Vienna in 1908. He obtained his doctorate in physics at the University of Gottingen where he studied under Max Born and James Frank.

In 1931 he became assistant to Heisenberg at Leipzig and one year later joined Schrödinger in Berlin. After a period of some months at Kharkov in the U.S.S.R., Prof. Weisskopf moved first to Zurich and then to Copenhagen before taking up an appointment as professor at the University of Rochester in the United States. He remained at Rochester until 1943, spent about two years at Los Alamos, and then went to Massachusetts Institute of Technology in October 1945 to teach physics.

Uranium carbide in fuel

Mr. H. S. Kalish, chief of nuclear metallurgy at the metallurgical laboratories of Olin Mathieson Chemical Corporation, speaking at the 42nd National Metal Exposition and Congress, said that uranium carbide shows promise of becoming an important nuclear fuel material because of its high uranium atom density, good thermal conductivity and good irradiation stability.

His paper on powder metallurgy fabrication of uranium carbide was part of a conference on ' Non-oxide Compounds for Nuclear Fuels ', sponsored jointly at the Congress by the American Society for Metals and the Atomic Energy Commission.

One of the major problems with uranium carbide is the development of an economic method for fabricating the compound on a production basis that will result in the needed compositional control.

A major emphasis in research has been placed on the preparation of uranium carbide by reacting uranium metal with hydrogen to form a hydride and, subsequently, reacting the resultant uranium powder with methane or propane.

From the investigations done so far, it appears that in order to produce a high-density product from the powder it will be necessary to have a controlled amount of free uranium and, perhaps, significant quantities of oxygen or nitrogen in the material, particularly if cold pressing and sintering techniques are to be resorted to.

Lecture course

Borough Polytechnic in London is having a course of 13 lectures on nuclear power technology, to be given on Thursday evenings commencing on January 12 at 7 p.m. An elementary knowledge of nuclear and reactor physics will be assumed. Further details can be obtained from the secretary, Borough Polytechnic, Borough Road, London, S.E.1.

Power economics

Prospects of improvements in the technology of nuclear power generation resulting in a reduction in costs are indicated in a report on nuclear power economics prepared by the International Atomic Energy Agency.

It states that important cost reductions can be expected from technical advances that are likely to emerge from the continuous research and development that are going on in several fields. Especially significant will be possible reductions in fuel cycle costs, resulting from lower fabrication and reprocessing charges, higher burn-ups and a fall in uranium prices. Development of improved but low-cost reactor materials will also result in an overall economy. Sizeable savings can be expected from the standardisation of reactor components.

With a better understanding of the essential safety requirements, containment and control of reactors will become simplified and less expensive. When several nuclear power plants of essentially the same design are built, the engineering development expenses will be spread out and the cost per unit will decrease.

Swedish reactor for 1965

A.K.K., a combine of Swedish private and municipal power producers, have recently been granted a permit by the government to build an atomic power plant at Simpvarp on the Baltic coast.

While no decision has yet been taken as regards the type of reactor to be used it will probably be an enriched-uranium unit in the 50 to 60-MW class.

Binding tenders for the project have been submitted by Asea and Nohab on the one hand and by Kockums on the other. Both Swedish groups have collaborated with American companies in connection with their respective tenders. A final order is not likely to be given before the end of this year, but the plant is scheduled to go into operation in 1965. It is expected that between two-thirds and three-quarters of the total deliveries of equipment will be made from Swedish firms.

Moire fringe light diffraction

A piece of laboratory equipment which makes use of Moire fringe light diffraction patterns to determine the height of a liquid in a tube or a burette to within 0.01 in. has been devised by A.W.R.E.'s chemical engineers.

It can be worked by direct, automatic or remote control and can be arranged to feed information into an electronic counter or to a pen recorder.

One application is in micro-analyses of radioactive liquids.

The heart of the device is a mobile ' carriage ' which is assembled around the burette. One half contains a light source, a fixed and a movable grating and a photocell, and the other, on the opposite side of the burette, two photocells.

Operations begin with the carriage at the top of the device. Light passes through a 0.02-in. slot in the carriage, and through the two gratings to the photocell. As the carriage moves,

£ s d

CHEMICAL PLANT COSTS

Cost indices for the month of November 1960 are as follows:

Plant Construction Index: 181.0

Equipment Cost Index: 169.8

(June 1949 = 100)

£ s d

Moire fringes are produced by the relative movement of the two gratings so that the light to the cell is cut off once for each grating line, *i.e.* in this case every 0.01 in.

Although these light flashes to the cell are going on all the time in the downward sweep they are recorded only between a zero shield and the meniscus of the liquid.

Irradiating natural rubber

By varying radiation dose to natural rubber latex the molecular structure can be altered at will. This was brought out in a report of a Goodyear Tyre & Rubber Co. research team.

Although results depicted in the report are based on preserved concentrated latex, it is assumed that comparable data would be obtained using fresh natural latex. This would permit the irradiation to be done at the plantation site.

The team used cobalt-60 gamma rays for its experiments, with doses of from 1 to 20 megarads. Results indicate that natural rubber latex irradiation treatments could be easily accomplished on a commercial scale at the plantations with either electron accelerating machines or radioactive isotopes.

Irradiation of latex provides a practical and economical method of altering the natural rubber polymer so it has improved properties. The radiation initiates a cross-link formation within the polymer. This leads to increased modulus and substantially higher tensile strength, with strength increasing with the degree of radiation dose.

Several additives, such as methyl methacrylate and a high-styrene resin latex, improved and aided compression of foam rubber still further when added to the natural latex rubber prior to irradiation.

College reactor

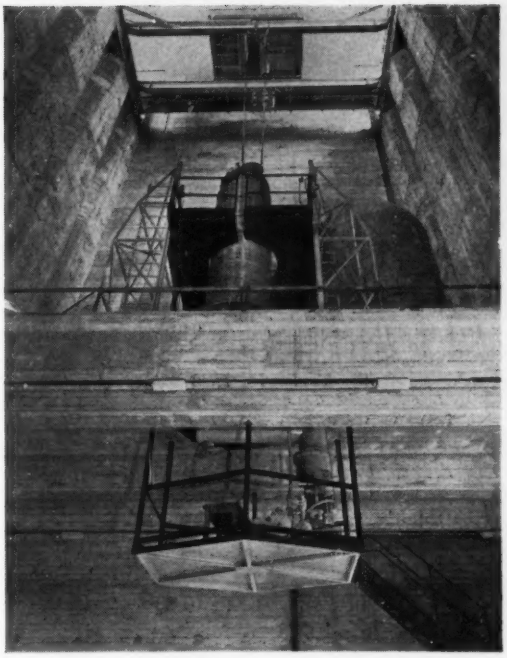
The JASON Mark III reactor, made by Hawker Siddeley Nuclear Power Co., has been designed to meet the requirements of the Queen Mary College department of nuclear engineering for a reactor to act as a source of neutrons to drive fuel element lattice experiments.

Capable of driving three such experiments at the same time, the JASON Mark III has similarities to NESTOR being supplied to the U.K.A.E.A. at Winfrith, and the JASON operating at the manufacturer's works at Langley.

With a continuous power of 10 kW this reactor is expected to be the first university reactor to be installed in London and offers Queen Mary College facilities already possessed by many universities in the U.S.A.

VAN DE GRAAFF TOWER

The interior of the Van de Graaff tower of the Centro Informazioni Studi Esperienze (C.I.S.E.). The new laboratories at Segrate, near Milan, were opened recently. C.I.S.E. is a research institute in the field of peaceful applications of nuclear energy. It is by statute a non-profit-making concern equally financed by two groups of private and public shareholders



Nuclear ship symposium

The I.A.E.A. nuclear ship symposium, held recently at Taormina, ended on a strong note of optimism as far as safety aspects are concerned.

It is evident that nuclear ships can be made safe—that is, that the risks that are implied in any human progressive undertaking can be kept to a minimum and clearly be classified as acceptable.

It is also clear from the talks that there is no prospect of having nuclear ships economically competitive with conventional ships in the near future. Most participants urged, however, that, as the economic gap was closing, it would be necessary and prudent to design, construct and operate nuclear ships so that the necessary experience could be gained in the only really effective way—under actual sea-going conditions.

Radiation pyrometer

A radiation pyrometer and associated electrical circuits capable of continuously measuring surface temperatures of metal bars in the range 650° to 750°C., travelling at rates up to 20 ft./min., has been built by the development and engineering group of the U.K.A.E.A.

Measurement is effected in a narrow band ($\frac{1}{2}$ to $\frac{3}{4}$ in.) between a heating zone and a quenching zone.

A heat radiation transmission path is provided by a fused quartz rod, the receiving end of which is shaped like a fish tail and partly encircles the bars. At its other end is a lead sulphide photocell.

The quartz rod has two breaks, the first for a rotary radiation chopper in the form of a slotted disc turning at a speed to give a chopping frequency of 1,000 counts/sec., the second for a radiation chopper having alternate blades of perspex and germanium and giving a 10-c/s. frequency.

Finland's reactor

The board of governors of I.A.E.A. approved the request of the Finnish Government for the supply of a 100-kW TRIGA Mark III training and research reactor and for the enriched uranium needed as fuel for it.

Both the reactor and the fuel are to be supplied by the U.S. under a trilateral agreement between the agency and the two governments concerned.

Finland has agreed to accept agency safeguards to be attached to the reactor and to the special fissionable material. The exact terms of these safeguards will be laid down in an exchange of letters to be approved by the agency's board of governors.

The price charged for the nuclear fuel will be the same as that in force for domestic transactions in the U.S. —about $42,000.

CPE Diary

JANUARY 12 Lecture on **metallurgical research at high pressures** to be given by Dr. J. E. Hilliard, of the Research Laboratory of U.S. General Electric Co., at 6.30 p.m. at the Institute of Metals, 17 Belgrave Square, London, S.W.1.

JANUARY 12 TO 13 Course on the **disposal of waste from the uses of radioisotopes** to be held at the Manchester College of Science and Technology. Details from the Registrar, College of Science and Technology, Manchester 1.

JANUARY 16 TO 20 **Exhibition of the Institute of Physics and the Physical Society** to be held at the Royal Horticultural Society's Old and New Halls, London, S.W.1. Details from A. C. Stickland, 47 Belgrave Square, London, S.W.1.

JANUARY 18 TO 19 Symposium on **pressure vessel research towards better design** organised by the Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

JANUARY 24 Lecture on **mass transfer in drops and bubbles** at the Geological Society, Burlington House, London, W.1, at 5.30. Details from the Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1.

FEBRUARY 6 TO 17 Practical course in **radiation safety and health physics** at the Liverpool College of Technology. Details from J. W. Lucas, College of Technology, Byrom Street, Liverpool 3.

FEBRUARY 6 TO 17 Practical course in **radiochemistry — continuation of reactor technique and application of isotopes** course to be held in Karlsruhe, Germany. Details from Kernreaktor Bau- und Betriebsgesellschaft mbH., Weberstrasse 5, Karlsruhe, Germany.

FEBRUARY 14 TO 17 Symposium on **light metal industry in India** to be held at Jamshedpur. Details from National Metallurgical Laboratory, Jamshedpur 7, India.

FEBRUARY 15 Lecture on **science and the developing countries** by Prof. Blackett at the Geological Society, Burlington House, London, W.1. Details from the Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1.

FEBRUARY 20 Lecture on **controlled fusion reactions** by Prof. Blackett organised by the Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

FEBRUARY 20 Meeting of the nuclear energy group of the Institution of Mechanical Engineers on the **influence of availability of enrichment on reactor type and design.** Details from the Institution, 1 Birdcage Walk, London, S.W.1.

FEBRUARY 23 Lecture by Prof. W. Hume-Rothery on the **theory of the alloys of copper** to be held at the Royal Institution, Albemarle Street, London, W.1. Details from the Metal Physics Committee of the Institute of Metals, 17 Belgrave Square, London, S.W.1.

MARCH 1 TO 2 Symposium on **user experience of large-scale industrial vacuum plant** to be held in London. Details from the organisers, the Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

MARCH 5 TO 6 Practical course in **radiochemistry** to be held in the Liverpool College of Technology. Details from J. W. Lucas, College of Technology, Byrom Street, Liverpool 3.

MARCH 7 Papers on **fluidisation** from A.E.R.E. Harwell at the Geological Society, Burlington House, London, at 4 p.m. Organised by the Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1.

MARCH 21 Discussion meeting of the Institution of Chemical Engineers on **some factors in the safe operation of air separation plants** at the Geological Society, Burlington House, London, W.1, at 5.30 p.m. Details from the Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1.

Technical Press in January . . .

A number of articles appearing in our associate journals this month will be of interest to readers of CPE. Specimen copies and subscription forms are available from the Circulation Manager, Leonard Hill House, Eden Street, London, N.W.1.

Manufacturing Chemist — Special feature on safety equipment and industrial health hazards by V. A. Broadhurst. Carbohydrates in the chemical industry—2, by G. Machell. Hydrocarbon solvents for locust control, by A. D. Harford. Evans vaccine factory at Liverpool.

Petroleum—History and structure of world's largest petroleum company —Standard Oil, New Jersey, by T. H. H. Skeet. Sizing of vapour relieving systems, by J. Conison. Review on fire equipment and safety. Disposal of refinery acid sludge—1, by P. W. Sherwood. Canadian natural gas developments.

Fibres and Plastics—Special feature on glass-fibre applications. Stabilisation of PVC, by D. P. Dodgson. Chemical constitution and methods of dyeing polyamide fibres—3, by R. S. Asquith. Structural aspects of bonding—2, by J. A. Van den Akker.

Paint Manufacture—Flooding and floating in paints, by L. A. Logue. Advanced paint chemistry—14, by P. M. Fisk. Report on American Chemical Society's conference on high polymers, by H. Warson.

Dairy Engineering — Manufacture of instant milk, by C. W. Hall and T. I. Hedrick. Choice of materials for pipelines, by H. T. Hoblyn. Report on Dairy Industries Exposition in Chicago, by D. E. Seiberling.

Automation Progress—Computers and the new technology, by D. E. Green. Hydraulic servomechanisms —1, by D. E. Turnbull. Russia in retrospect, by A. D. Booth.

World Crops—F.A.O. world seed campaign, by R. O. Whyte and J. J. de Jong. Production of high-quality seed, by H. N. Greenwood and D. H. Peto. Protection of grain in storage by J. P. Brooke. Special feature on seeds and grain handling.

Food Manufacture—Special feature on mixing. Factory visit to C.W.S. biscuit factory, Crumpsall. Annual reviews on confectionery, by D. R. Felstead, and ice cream, by E. L. E. Humphriss.

Corrosion Technology — Influence of water movement on corrosion of ferrous materials, by G. Butler. Enhanced corrosion resistance through electro-polishing. PVC pipes in the chemical and gas industries, by A. Trebucq.